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(71)(72) Applicant and Inventor: ADELMAN, Roger, A. [US/US]; 1562 Wittlow Place, Cincinnati, OH 45224 (US).

(74) Agents: LILES, James, D. et al.; Frost & Jacobs, 201 East 5th Street, 2500 Central Trust Center, Cincinnati, OH 45202 (US).

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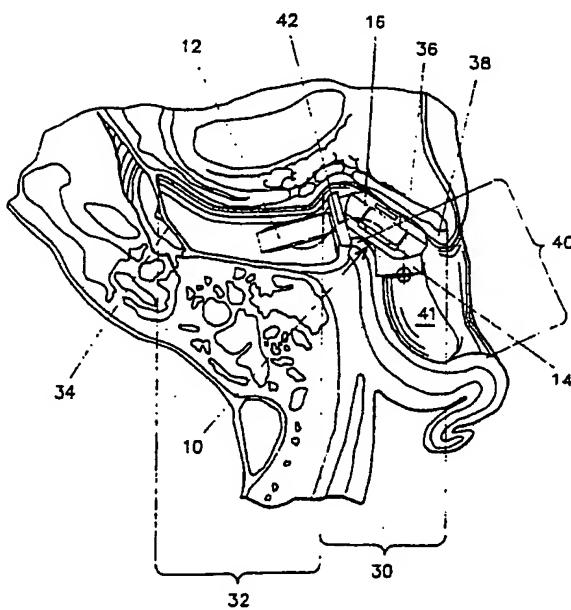
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(54) Title: IMPROVED HEARING APPARATUS

(57) Abstract

A hearing aid is configured and dimensioned so as to be inserted past the cartilaginous part (30) of the external auditory canal (external acoustic meatus) and into the bony part (32) of the external auditory canal. The outer portion of the hearing aid fits snugly into the cartilaginous part (30) of the external auditory canal; the microphone (14) is located at the acoustic focus (36) of the ear such that the natural sound and direction gathering functions of the human outer ear are fully utilized by the hearing aid. The inner portion of the hearing aid is articulately joined to the outer portion to enable the inner portion to be positioned past the sigmoid portion (42) of the external auditory canal and forms a soft covered, elongated speaker (12) which fits within part of the bony part (32) of the external auditory canal, without causing discomfort to the human user.



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IMPROVED HEARING APPARATUSTECHNICAL FIELD

5 The present invention relates generally to hearing aids and listening devices and is particularly directed to a hearing aid that is physically dimensioned and configured to fit inside the external auditory canal (external acoustic meatus). The invention will be specifically disclosed in connection with a miniature hearing aid which has an outer portion located at the acoustic focus of the concha, having a microphone at this important focal point, and which has an inner portion located partially within the bony part of the external auditory canal, having an elongated speaker that is "closely-coupled" to the tympanic membrane.

20

BACKGROUND ART

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Hearing aids are generally well-known in the art and in wide spread use. In a typical hearing aid, a microphone is used to pick up sound waves and convert that information into electrical signals. An audio amplifier magnifies the electrical signals within the frequencies of interest (20 Hz to 20 KHz), and then sends the amplified signals to a speaker located at the inner portion of the hearing aid. The speaker converts the electrical signals back into sound waves. In technical literature concerning hearing aids, speakers are often referred to as "receivers".

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Many conventional hearing aids are relatively large devices that are quite visible to other persons. A recent trend has been to make the hearing

1 aid as small as possible, and to place a portion of
it inside the ear where it is not visible. There are
several patents which disclose hearing aids that
ostensibly fit within the external auditory canal.
5 It must be noted that, even in such patented
inventions disclosing "in-the-canal" hearing aids, a
portion of the hearing aid is visible and noticeable
to other persons because the speaker and the
electronics are too large to fit within the external
10 auditory canal. One exception is disclosed in U.S.
Patent No. 4,817,609 by Perkins, wherein the external
auditory canal is surgically enlarged so that the
disclosed hearing aid can fit deep inside the canal,
thereby showing very little to outside observers.
15 Such surgery is an extraordinary remedy that most
human users would wish to avoid if a more
satisfactory hearing aid were available.

20 Other U.S. Patents that disclose hearing aids
which ostensibly fit within the external auditory
canal do not depict the exact anatomy of the external
auditory canal. The external auditory canal
(external acoustic meatus) leads from the concha (the
"bowl" of the ear) to the tympanic membrane
(eardrum). The outer one-third of the canal is
25 cartilaginous, and the inner two-thirds is bony. The
canal is not straight, but in the horizontal plane (a
Transverse Section--see Fig. 3A) it takes a sharp
turn, approximately 90°, toward the rear, and then a
milder turn back toward the front as the path is
30 traced from the concha toward the tympanic membrane.
The area containing these "S-shaped" turns is
designated the sigmoid portion of the cartilaginous
part of the external auditory canal. Hearing aids
35 that are disclosed as "straight" in overall shape are
just not able to be located within the external

1 auditory canal. Three patents that disclose such
hearing aids are U.S. Patent No. 4,520,236, by
Gauthier, No. 4,539,440, by Sciarra, and No.
4,706,778, by Topholm.

5 The Gauthier patent describes a hearing aid that
snugly fits inside the external auditory canal,
apparently including the bony part of the canal. The
hearing aid appears (from the drawings) to extend the
10 entire length of the auditory canal, virtually
against the tympanic membrane; such a device would
surely be very uncomfortable to wear. Additionally,
the Gauthier patent discloses the use of an earmold
that would contain the device. Unless the earmold
15 was very flexible, it would be impossible to insert
the hearing aid into its intended location inside the
external auditory canal; a "straight" configuration
needed to snugly fit into the inner (bony) part of
the canal would not be able to be placed through the
20 sigmoid portion of the external auditory canal.

25 The Sciarra patent describes a hearing aid that
has an adjustable diameter, which can be expanded
(enlarged) in order to fit snugly inside the external
auditory canal. The patent does not disclose
precisely where the hearing aid is to sit in the
canal. Since the drawings illustrate a "straight"
device, it obviously cannot be placed very far into
the canal, because it would not be able to make it
30 through the sigmoid portion of the external auditory
canal.

35 The Topholm patent describes a hearing aid that
has a hollow space at its innermost tip, which acts
as a resonance chamber by enhancing the device's
frequency response in the 1000 Hz to 5000 Hz range.

1 The patent does not disclose the location in the
external auditory canal wherein the hearing aid is to
be placed, nor does it disclose the exact shape of
the entire hearing aid. All that is disclosed is a
5 general tubular shape of the innermost tip, and it
appears to fit somewhere in the cartilaginous part of
the external auditory canal.

10 Another U.S. patent which discloses a hearing aid
that ostensibly fits in the external auditory canal
is No. 4,937,876, by Biermans. This patent does not
disclose where the hearing aid is to sit in the
external auditory canal. The drawings disclose a
15 device which has a "receiver" (speaker) near its
inner tip, with such speaker aiming directly toward
the tympanic membrane. It is clear, however, that
the speaker is too large in diameter to fit through
the sigmoid portion of the external auditory canal,
and therefore, this invention merely fits into the
20 exterior opening of the external auditory canal with
the major portion of hearing aid sticking outside the
area of the concha.

25 It is important to note that, in order to
minimize distortion in sound energy transferred to
the tympanic membrane, a hearing aid speaker should
have a surface area equal or greater than the surface
area of the tympanic membrane. Since the surface
area of the tympanic membrane is at least as great as
an oblique cross-section area of the external
30 auditory canal (as can be seen in FIGS. 3A and 4A of
the present invention), it is therefore, obvious that
a miniature speaker whose face is pointed directly at
the tympanic membrane (as in the Biermans patent)
must be at least as large as the cross-section area
35 of the external auditory canal. The inevitable

1 conclusion is that such a speaker cannot possibly fit
past the sigmoid portion of the cartilaginous part of
the external auditory canal.

5 The above four patents attempt to disclose
hearing aids that are to be located in the external
auditory canal. It is clear, however, from their
general shape and size that a major portion of each
10 of these devices must stick out of the ear in a
manner that would be visible to others. Either the
device is too "straight" to fit past the sigmoid
portion of the external auditory canal, and/or the
15 electrical components (including a battery) must
reside outside the sigmoid portion of the canal due
to their large overall size. Hence, the need for a
miniature hearing aid that is small enough and
properly shaped to fit deep inside the external
20 auditory canal (without requiring ear surgery) has
not yet been met by the above patented devices.

25 An improvement in the art was disclosed in U.S.
Patent No. 4,870,688, by Voroba. The Voroba patent
describes a modular hearing aid which is shaped (and
sized) to partially fit in the external auditory
canal such that a large portion of the device is
hidden from view by an outside observer. A portion
25 of the device extends into the inner portion of the
canal past the sigmoid portion of the external
auditory canal. As the Voroba patent discloses, it
is desirable to have the hearing aid extend further
30 into the external auditory canal since the closer the
hearing aid is to the tympanic membrane (eardrum),
the greater the effective sound output of the hearing
aid. The Voroba hearing aid uses a number of "hard"
35 components, having individual geometries which
provide for the accommodation of anatomical

1 variations in individual users. The collection of
modular hard parts are at least partially enclosed
and extended by a compliant covering. The covering
5 of the inner portion of the Voroba hearing aid is
made of soft (compliant) material, and it may
penetrate up to 3/4 of the length of the external
auditory canal, thereby increasing the effective gain
of the hearing aid by 6 to 10 dB over conventional
"in-the-canal" hearing aids.

10 It must be noted, however, that the Voroba
invention does not place its speaker at the innermost
portion of the device. The speaker is, instead,
located further toward the outer portion of the
15 device (approximately in the center of the device
according to the drawings), and a sound-carrying
tube, surrounded by soft, resilient material, extends
to the innermost tip of the device. In effect, the
speaker (called a "receiver" in the Voroba patent)
emits sound waves into the tube, and the tube acts as
20 a passive wave guide toward the inner portion of the
external auditory canal, and toward the tympanic
membrane. The Voroba patent, therefore, only teaches
the concept used in the prior art of having passive
25 elements in the innermost portion of the hearing
aid. Such passive elements are merely
space-consuming conduits which transfer the acoustic
energy from the active, sound-generating surface of
the speaker. The air inside such passive element is
30 compressible, so this system still lacks a certain
amount of efficiency, and compromises the faithful
reproduction of the soundwave at the tympanic
membrane. In essence, the overall system of hearing
aid speaker to tympanic membrane is not
"closely-coupled."

1 Close coupling of an acoustic source to the
tympanic membrane is necessary for the realization of
the beneficial attributes gleaned by signal
processing for the treatment of hearing deficit.
5 Devices in the prior art for generalized signal
processing, including U.S. Patent No. 4,637,402 by
Adelman, and Patent Numbers 4,882,762, and 4,882,761
by Waldhauer, demonstrate optimization techniques for
manipulating the electronic representation of the
10 audio signal, but fail to provide optimal
presentation as a sound wave to the tympanic
membrane. Thus, generalized signal processing
techniques of the prior art are limited by the
ability of the output transducing device (the
15 speaker) and, therefore, are not closely coupled
systems.

20 To achieve a more closely-coupled system, the
amount of compliant material between the active face
of the speaker and the receptive face of the tympanic
membrane must be kept to a minimum. The best method
to achieve such a system is to reduce the volume of
air (thereby reducing the amount of compliant
material) contained in the active path of the sound
waves. The beneficial effects of such a system are
25 (1) better bandwidth, (2) greater efficiency of
energy transmission, and (3) reduced distortion of
the auditory signal. A better method for achieving
such a closely-coupled system is to locate the active
speaker itself inside the external auditory canal, as
30 close to the eardrum as feasible, while also keeping
the amount of compliant material (the amount of air
volume) in the system to a minimum.

1

SUMMARY OF THE INVENTION

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Accordingly, it is a primary object of the present invention to provide a hearing aid that is properly shaped, sized, and oriented to fit within the external auditory canal, causing the speaker element to fit in the canal at a point between the sigmoid portion of the canal and the tympanic membrane.

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It is another object of the present invention to provide a hearing aid that is properly shaped, sized and oriented to fit within the external auditory canal, with the speaker element located in the canal between the sigmoid portion of the canal and the tympanic membrane, whereby the hearing aid is covered by a disposable boot that prevents contamination and seals the external auditory canal so that the volume of air between the hearing aid and the tympanic membrane is held constant.

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It is yet another object of the present invention to provide a hearing aid that is properly shaped, sized, and oriented to fit within the external auditory canal, whereby the speaker element has an elongated shape so as to not only fit deeply in the canal between the sigmoid portion of the external auditory canal and the tympanic membrane, but also to allow the speaker to exhibit a "high-fidelity" frequency response in the human hearing range of 20 Hz to 20 KHz, and to minimize distortion.

35

A further object of the present invention is to provide a hearing aid which has an inner portion that is properly shaped, sized, and oriented to fit within the external auditory canal, whereby the outer

1 portion (the microphone and the electrical, electronic, and signal processing components) may be miniaturized to an extent that, while it is in use, the outer portion of the hearing aid is barely
5 noticeable to another person who is observing the user.

10 A yet further object of the present invention is to provide a hearing aid which has an inner portion that is properly shaped, sized, and oriented to fit within the external auditory canal, whereby the microphone in the outer portion is located at the acoustic focus of the concha, thereby utilizing the natural sound gathering and direction locating
15 anatomical features of the human ear to the greatest possible extent.

20 A still further object of the present invention is to provide a hearing aid that is properly shaped, sized, and oriented to fit within the external auditory canal, whereby the external tip of the hearing aid at the microphone contains a large on-off control which can be actuated by the fingertip of the human user, and can also be used as a volume control,
25 and a "treble-bass" filter control.

30 It is yet another object of the present invention to provide a hearing aid that is properly shaped, sized, and oriented to fit within the external auditory canal and has its microphone at the acoustic focus of the concha, whereby a hand-held transmitter
35 is used to adjust the volume level and the treble-bass filter of the hearing aid. Such a hand-held transmitter could use radio frequency electromagnetic radiation to carry the necessary information to the hearing aid, or it could use other

1 wavelengths of electromagnetic radiation to carry the
information, such as ultraviolet, infrared, or
microwave frequencies. Ultrasonic sound waves could
even be used to perform the above task.

5 It is still another object of the present
invention to provide a hearing aid that is properly
shaped, sized, and oriented to fit within the
external auditory canal and has its microphone at the
10 acoustic focus of the concha, whereby a radio link is
also used to provide signal processing by a remote
computer linked to the hearing aid. Such signal
processing can be used to enhance certain
frequencies, remove background noise, or to remove
15 other unwanted sound patterns.

20 A still further object of the present invention
is to provide a hearing aid that is capable of
amplifying or attenuating the conductive sound
(conducted through the bones) that is created by the
25 human user's own voice.

25 A yet further object of the present invention is
to provide a hearing aid that is properly shaped,
sized, and oriented to fit within the external
auditory canal, and to combine a radio receiver as an
input to the amplifier such that the hearing aid
speaker would output both information received from a
radio station, and sound wave information received by
the hearing aid input microphone (at a reduced
30 volume, if desired). Such received radio frequencies
could be in the commercial AM and FM bands.

35 Additional objects, advantages and other novel
features of the invention will be set forth in part
in the description that follows and in part will

1 become apparent to those skilled in the art upon
examination of the following or may be learned with
the practice of the invention. The objects and
5 advantages of the invention may be realized and
obtained by means of the instrumentalities and
combinations particularly pointed out in the appended
claims.

10 To achieve the foregoing and other objects, and
in accordance with the purposes of the present
invention as described herein, an improved hearing
aid is provided having substantially small overall
size and the correct shape to fit in the external
auditory canal of the human ear. The speaker element
15 of the hearing aid is placed within the canal at a
point between the sigmoid portion of the canal and
the tympanic membrane. The hearing aid is covered by
a disposal boot that prevents contamination of the
functional parts of the hearing aid and seals the
external auditory canal around the hearing aid so
20 that the volume of air between the hearing aid and
the tympanic membrane is held constant. The central
portion of the boot consists of a deformable
material, so that one size of hearing aid will fit
most human users. This deformable material tends to
25 retain its original size and shape, such that it will
press snugly against the inner diameter of the
external auditory canal of the user's ear,
particularly at the entrance to the external auditory
canal. This deformable material seal also serves as
30 a sound insulator which prevents feedback from the
speaker to the microphone of the hearing aid.

35 The fact that the deformable boot tends to seal
the volume of air inside the external auditory canal,
between the point that the hearing aid makes contact

1 with the inner membrane of the user's ear and the
5 tympanic membrane, is important to achieve a
10 closely-coupled system. As discussed above, to
achieve a closely-coupled system, the amount of
compliant material between the active face of the
speaker and the receptive face of the tympanic
membrane must be kept to a minimum. By sealing the
volume of air inside the overall system that consists
of the hearing aid, the air column, and the tympanic
membrane, the amount of compliant material (the air)
is minimized and kept constant, so that motion at the
speaker is accommodated only by a responsive motion
of the tympanic membrane, along with avoiding
unwanted resonances in the small volume of trapped
15 air.

20 In accordance with a further aspect of the
invention, the speaker element of the hearing aid has
an elongated shape so as to not only fit in the
external auditory canal between the sigmoid portion
25 of the cartilaginous part of the external auditory
canal and the tympanic membrane, but also to have a
large enough surface area to cause a sympathetic
vibration of the tympanic membrane. Such large sound
generating surface enables the speaker to produce
30 sound energy which is largely devoid of harmonic
distortion in the normal human hearing range of 20
Hertz to 20 Kilohertz. The overall cross sectional
shape of the speaker element is generally that of a
35 flattened tube. The acoustic output of the speaker
is created by a speaker membrane which is driven by
an electromagnetic linear motor. In one embodiment,
the linear motor consists of a permanent magnetic
field and an oval-shaped current-carrying coil which
is disposed within the magnetic field. The coil is
permanently affixed to the speaker membrane (its

1 face), forming an armature. A portion of the speaker
structure consists of one or more resonance cavities
on the interior of the speaker membranes tunably
suitable for the enhancement of certain portions of
5 the frequency spectrum. The speaker must consist of
at least one armature that forms the speaker's face,
however, in a second embodiment, there are two
separate faces, on opposite sides of the speaker.
10 Each of these two faces may have its own resonance
cavity and its own compliant properties, thereby
allowing each speaker face to be used for the
enhancement of a different portion of the frequency
spectrum, such as treble or bass.

15 According to a further aspect of the invention,
the speaker membrane is in the form of an oval plane
and has compliance enhancing ripples near its
attachment edges. A substantial portion of the plane
is movable as a rigid body, yet the ripples near its
20 attachment edges greatly enhance the performance of
the speaker in the form of greater efficiency.

25 In yet a further aspect of the invention, the
overall speaker portion of the hearing aid is
articulated at its attachment point to the rest of
the main body of the hearing aid. This allows the
speaker element to fit past the sigmoid portion of
the external auditory canal, and thereby allows the
entire speaker to fit inside the canal.

30 In yet another aspect of the invention, the
remaining components of the hearing aid, i.e., the
microphone and the electrical components, are
miniaturized to the extent that the entire hearing
35 aid is barely visible to another person who is
observing the user. This is made possible by

1 constructing the hearing aid such that the entire
5 speaker element fits inside the external auditory
 canal, and the portion of the hearing aid that
 contains the battery and the electronic components
10 fits at the very entrance of the canal, such that the
 microphone is located at the acoustic focus of the
 concha. As discussed above, the shape of the hearing
 aid and the configuration and orientation of its
 elements is very important so that the desired
15 location of its placement in a human ear is
 possible. As practiced by this invention, the entire
 hearing aid is substantially out of sight of another
 observer, except for the microphone itself, which is
 at the very entrance of the external auditory canal
 (i.e., at the acoustic focus of the concha). By
 locating the active elements of the entire hearing
 aid deeper in the external auditory canal, the
 hearing aid does not protrude out from the concha,
 and therefore, cannot be seen by others.

20 In yet another aspect of the invention, the
 microphone is located at the acoustic focus of the
 concha. This arrangement maximizes the natural sound
 gathering and direction locating anatomical features
25 of the human ear. Since the concha (the "bowl" of
 the ear) is naturally designed to be the focal point
 of sound entering the human ear, its acoustic focal
 point is also the logical location for a microphone
 of a hearing aid. Until the present invention,
 however, no hearing aid has been able to place the
30 microphone specifically at this point. While the
 type of microphone used in this invention is not
 crucial, it must, however, be small in size in order
 to fit inside the concha, and it should also operate
 using little electrical power. Two microphones
35 technologies that have been successfully utilized in

1 this invention are the electret, and the
5 piezo-electric types.

10 In a further aspect of the invention, the
5 electronics of the hearing aid include volume and
 tone (treble - bass) functions. The volume function
 can have an automatic gain control circuit, and the
 gain of the electronics can either be linear or
 non-linear, as necessary, to minimize or eliminate
10 distortion.

15 In accordance with yet another aspect of the
 invention, the external prominence of the hearing
 aid, essentially at the location of the microphone,
 contains an on/off control which can be actuated by
 the fingertip of the human user. Fingertip actuation
 of this control also provides a volume control and
 treble-bass filter control in one embodiment.

20 In accordance with a still further aspect of the
 invention, a hand-held transmitter is used to adjust
 the volume level and the treble-bass filter of the
 hearing aid. In one embodiment the hand-held
 transmitter uses radio frequency electromagnetic
 radiation to carry the necessary information to the
25 hearing aid. In a second embodiment, the transmitter
 uses electromagnetic radiation in the infrared
 frequency spectrum to carry the necessary information
 to the hearing aid. It is obvious that any safe
 frequency of electromagnetic radiation could be used
30 to carry the necessary information to the hearing aid
 over the short range required. Ultrasonic sound
 waves could even be used to perform this task.

35 According to yet another aspect of the present
 invention, a single-part hearing aid (which includes

1 substantially the same elements as in the single-part
hearing aid described above) is combined with a
self-contained enhanced signal processing unit. Such
enhanced signal processing can remove background
5 noise, enhance certain frequencies, or remove other
unwanted sound patterns. This aspect of the
invention can be utilized to greatly enhance the
performance of the hearing aid for persons having
particularly profound hearing dysfunction.

10 According to a yet further aspect of the
invention, a radio link is used to provide enhanced
signal processing to the hearing aid. Such signal
processing is performed by a remote signal processing
15 unit which can be used to enhance certain
frequencies, remove background noise, or also to
remove other unwanted sound patterns. The radio link
would be best utilized as a simultaneous two-way link
(full duplex) whereby the original sound is captured
20 by the microphone of the hearing aid portion of this
system (which consists of substantially the same
elements as in the single-part hearing aid described
above), then transmitted by the radio link to the
signal processing portion of this system. The signal
processing portion can be a portable unit, strapped
25 to the user's clothing, or it can be a stationary
unit for non-mobile use. After processing, the
information is retransmitted from the signal
processing portion by radio link back to the hearing
aid portion for transfer to the speaker output of the
30 hearing aid. This remote enhanced signal processing
portion is available when the electronic elements are
too large in size, or are too great in electrical
power consumption to fit within the anatomical
35 limitations of the above-described single part
hearing aid. This aspect of the invention can be

1 utilized to greatly enhance the performance of the hearing aid for persons having particularly profound hearing dysfunction.

5 According to a still further aspect of the invention, use of an accelerometer or other rigid body motion sensing device cancels or enhances the conductive sound that is created by the human user's own voice. Such sound waves are conducted through
10 the solid structure of the speaker's head into the temporal bone, which conducts the sound waves directly into the cochlea of that speaker's ear. Depending upon the hearing needs of the particular user of the hearing aid, such conductive sound would
15 be best enhanced or attenuated by the hearing aid. In this aspect of the invention, the accelerometer or other rigid body motion sensor is attached to the surface of the hearing aid at a point where it most closely comes in contact with the solid portion of
20 the external auditory canal. In this way, the accelerometer can sense directly the conductive sound waves created by the human user's own voice. Such sound waves would then be either amplified or attenuated, and then mixed with air-borne sound
25 detected by the microphone according to the user's needs. The degree of amplification, attenuation, or mixing could be controlled by the previously mentioned hand-held transmitter, or through a separate control that the user could actuate with his
30 fingertip.

35 In yet a still further aspect of the invention, a radio receiver is also placed inside the hearing aid such that the hearing aid speaker would output information received from both the radio station, and sound wave information received by the hearing aid

1 input microphone. The most common set of radio
frequencies that would be received would be the
commercial AM and FM bands of frequencies. Once
again, it would be desirable to be able to adjust the
5 volume of the received radio frequencies independent
of the volume received by the microphone. Such
volume controls could be located in the previously
mentioned hand-held transmitter, or by a fingertip
control.

10 In accordance with another aspect of the
invention, no external air vent is required to tune
the acoustical pathway between the speaker and the
eardrum. The possibility of "whistling," because of
15 feedback from the speaker to the microphone, via that
type of conduit is entirely eliminated. Very high
amplification is thus possible in a miniaturized
hearing aid that fits in the external auditory canal
without the bothersome quality of "whistling."

20 Still other objects of the present invention will
become apparent to those skilled in this art from the
following description wherein there is shown and
described a preferred embodiment of this invention,
simply by way of illustration, of one of the best
25 modes contemplated for carrying out the invention.
As will be realized, the invention is capable of
other different embodiments, and its several details
are capable of modification in various, obvious
aspects all without departing from the invention.
30 Accordingly, the drawings and descriptions will be
regarded as illustrative in nature and not as
restrictive.

1

BRIEF DESCRIPTION OF THE DRAWINGS

5

The accompanying drawings incorporated in and forming a part of the specification illustrate several aspects of the present invention, and together with the description serve to explain the principles of the invention. In the drawings:

10

FIGS. 1A-1E show several views of the complete hearing aid device constructed in accordance with the principles of the present invention;

15

FIG. 1A is a cross-sectional elevation view of the entire device constructed in accordance with the principles of the present invention;

20

FIG. 1B is a top plan view of the hearing aid device of FIG. 1A;

25

FIG. 1C is an elevational view of the hearing aid device of FIG. 1A, showing the details of a disposable boot in cross-section, including its deformable material portion;

30

FIG. 1D is a partial cross-sectional view taken along line 1D-1D of FIG. 1A;

FIG. 1E is a bottom plan view of the hearing aid device of FIG. 1A, illustrating a loop antenna in the base;

FIG. 2 is an oblique view of a human head, showing the anatomical sections designated as the coronal section, and the transverse section;

35

1 FIG. 3A shows the correct anatomical view of the
transverse section of the human ear, taken along line
3-3 in FIG. 2;

5 FIG. 3B shows the same view as FIG. 3A, however,
it includes the placement of the hearing aid device;

10 FIG. 4A shows the correct anatomical view of a
coronal section of the human ear, taken along line
4-4 in FIG. 2;

FIG. 4B shows the same view as FIG. 4A, however,
it also includes the placement of the hearing aid
device;

15 FIGS. 5A-5C show the details of the speaker
portion of the hearing aid device of FIG. 1A;

20 FIG. 5A is a plan view of the speaker portion of
the hearing aid device of FIG. 1A, and a
cross-sectional view of its articulated joint;

25 FIG. 5B is a longitudinal cross-section view of
the speaker portion, taken along line 5B-5B of FIG.
5A;

FIG. 5C is a sectional view of the speaker
portion, taken along line 5C-5C of FIG. 5B;

30 FIGS. 6A-6C show the details of the outer cover
of the hearing aid device of FIG. 5A;

FIG. 6A is a plan view of the speaker cover of
FIG. 5A;

1 FIG. 6B is a cross-sectional elevation view of
the speaker cover, taken along line 6B-6B of FIG. 6A;

5 FIG. 6C is a cross-sectional elevation view of
the speaker cover, taken along line 6C-6C of FIG. 6A;

FIGS. 7A-7C show the details of the armature of
the hearing aid device of FIG. 5A;

10 FIG. 7A is a plan view of the speaker armature of
FIG. 5A;

FIG. 7B is a cross-sectional elevation view of
the armature, taken along line 7B-7B of FIG. 7A;

15 FIG. 7C is a cross-sectional elevation view of
the armature, taken along line 7C-7C of FIG. 7A;

20 FIGS. 8A-8C show details of the microphone using
an electret device;

FIG. 8A is a top plan view of a microphone used
in the hearing aid device of FIG. 1A;

25 FIG. 8B is a cross-sectional elevation view of
the microphone of FIG. 8A;

FIG. 8C is an enlargement of the upper right hand
corner portion of FIG. 8B;

30 FIGS. 9A-9C show an alternative microphone using
a piezo electric device;

35 FIG. 9A is a top plan view of an alternative
microphone for the hearing aid device of FIG. 1A;

1 FIG. 9B is a cross-sectional elevation view of
the microphone of FIG. 9A;

5 FIG. 9C is an enlargement of the upper right hand
corner portion of FIG. 9B;

10 FIG. 10 shows an accelerometer, used in the
hearing aid device of FIG. 1A;

15 FIG. 11 is an electrical schematic of the hearing
aid device of FIG. 1A having local controls.

20 FIG. 12 is an alternative electrical schematic of
the hearing aid device of FIG. 1A, in this case,
25 having a remote hand-held controller which
communicates to the hearing aid device;

20 FIG. 13 is another alternative schematic for the
hearing aid device of FIG. 1A which, in addition to
what is described in FIG. 12, also has a
accelerometer input;

25 FIG. 14 is another alternative electrical
schematic that shows a signal processing unit which
is remote to the hearing aid, and is in constant
communication with the hearing aid device of FIG. 1A;

30 FIG. 15 is an electrical schematic which shows a
remote hand-held device which communicates with the
hearing aid device of FIG. 1, which in addition,
contains a radio receiver.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

35 Referring now to the drawings, a preferred
embodiment of the hearing aid device 10 is shown,

1 containing a speaker portion 12, a microphone portion 14, and a main body portion 16. Several views of
5 these portions of the hearing aid device 10 are illustrated in FIGS. 1A-1E. FIG. 1B shows a preferred location for the electronic components of the device 10. An integrated circuit which makes up an accelerometer is illustrated shown as an electronic chip 50. An integrated circuit which contains the amplifiers and any transmitter and receiver components is illustrated as an electronic chip 52. A third electronic chip 51 for a third integrated circuit is disposed between chips 50 and 52, and can be used for additional transmitter components, as well as any desired supplemental 10 signal processing circuitry. Electrical connections from the speaker and microphone portions 12 and 14 to the electronic components are preferably made at the connection of electronic chip 51.

15

20 As illustrated in FIG. 1C, the hearing aid 10 is covered with a disposal boot 20, which is made of an open cell deformable foam material which has a memory. The portion 21 of the disposable boot 20 which fits over the speaker portion 12 is very thin, in the order of 1mm, and is shown with an exaggerated thickness in FIG. 1C for purposes of illustration. One of the functions of the disposable boot 20 is to seal the air inside the external auditory canal so that it cannot escape nor can any atmospheric air enter that area, once the hearing aid 10 is in 25 place. This is accomplished by increasing the thickness of the boot 20 in the portion 22 surrounding the articulated joint 102. Another function of the disposable boot 20 is to prevent 30 contamination of the hearing aid by acting as a shield against eye wax, (cerumen) and other 35

1 exfoliants of the epithelium of the ear canal.
Another feature of the disposable boot 20 is a
pull-off tab 24 which allows the user to grip that
portion of the disposable boot and pull the entire
5 hearing aid out from the user's ear.

10 As most clearly shown in FIG. 1D, the hearing aid
device 10 uses a power source, which in the preferred
embodiment comprises two batteries 54. The batteries
54 of the preferred embodiment are of the type 377
15 and are not connected in series, but are instead used
to provide a bipolar DC power source for the
electronics of the hearing aid. It is obvious that
other DC power sources could be used in lieu of the
batteries 54.

20 A detail of the loop antenna 78 is illustrated in
FIG. 1E. Such loop antenna 78 could be used for any
radio frequency transmitter or receiver devices that
might be used in conjunction with the hearing aid 10.

25 In order to understand the significance of
several aspects of this invention, it is necessary to
fully appreciate the precise anatomy of the human
ear. FIG. 3A is an anatomically accurate, transverse
30 section of the human ear showing the important
structural details relevant to the present
invention. Starting at the exterior point of the
ear, the curved surface of the concha 41 is
illustrated in the region bounded by the bracketed
35 lines 40 in the illustration of FIG. 3A. The
acoustic focus of the concha 41 is located at the
point identified by the numeral 36. The point 36 is
the location where the natural shape of the human ear
focuses incoming sound waves. The external auditory
canal is formed by two distinct portions. The outer

1 most portion of the external auditory canal, called
the cartilaginous part of the external auditory
canal, is the portion enumerated 30 between the two
bracketed lines. The innermost portion of the
5 external auditory canal is called the bony part of
the external auditory canal 32, and lies between the
innermost two bracketed lines. The tragus 38 lies at
the entrance to the external auditory canal opposite
10 the concha 41. The sigmoid portion of the
cartilaginous part of the external auditory canal is
the S-shaped dashed line identified by the numeral
42. The average inner diameter of the external
auditory canal is approximately 7 mm. At the
innermost portion of the external auditory canal lies
15 the tympanic membrane 34, which is also called the
eardrum. The effective surface area of the tympanic
membrane lies in the range of 30-35 square mm.

20 The same anatomical features of the human ear are
again accurately depicted in FIG. 4A, however, FIG.
4A is a coronal section of the human ear, which is
90° from the transverse section of FIG. 3A.

25 FIG. 3B depicts the hearing aid device 10
positioned in the human ear. As can be seen in FIG.
3B, the main body portion 16 of the hearing aid 10 is
located directly at the entrance of the external
auditory canal. The main body position 16 lies in
contact with, and is hidden from view by the tragus
30 38. The microphone portion 14 of the hearing aid 10
is advantageously located such that it is directly at
the acoustic focus of the concha 36 so that it
maximizes the natural sound gathering and direction
locating anatomical features of the human ear. The
35 speaker portion 12 of the hearing aid is located
entirely inside the external auditory canal, and it

1 fits past the sigmoid portion 42 of the cartilaginous
part of the external auditory canal. Quite
significantly, the speaker portion 12 is designed to
fit entirely inside the external auditory canal, yet
5 has a large enough surface area of active speaker
element to effectively vibrate the human tympanic
membrane 34.

10 The same elements of the hearing aid device 10
are described in the companion view, FIG. 4B, which
is a coronal section of the human ear. Again, the
microphone portion 14 of the hearing aid is located
at the acoustic focus of the concha 36, and the
speaker portion 12, which is clearly shown in this
15 view, is located entirely inside the external
auditory canal well past the sigmoid portion.

20 The speaker portion 12 of the hearing aid device
10 consists largely of a linear motor 100, which is
described in detail in FIGS. 5A-5C. The top cover
112 of the linear motor 100 consists of magnetically
permeable material. There are a number of air holes
104 of different sizes in the top cover 112. In the
embodiment of FIG. 5B, there is also a bottom cover
152, also consisting of magnetically permeable
25 material, and is constructed similarly to the top
cover, also having air holes (not shown). The entire
linear motor 100 is held together and surrounded by
an outer housing 140. In the preferred embodiment of
FIGS. 5A-5C, the outer housing 140 is made of
30 shrinkable plastic material. The outer housing 140
is pressed around the outer pole piece 132, which is
also called a banjo housing. The outer pole piece
132 is made of magnetically permeable material; in
the preferred embodiment it is made of soft steel.
35 The outer pole piece 132 extends through the ball of

1 the articulated joint 102, and is hollow in that
region, acting as a conduit for the electrical
conductors 118 that lead to the speaker coils 116 and
148. The articulated joint 102 allows the speaker
5 portion 12 to pivotally move in relation to the main
body portion 16, which allows the speaker portion 12
to easily fit in the external auditory canal.

10 The top speaker membrane 114 consists of a three
micron polyester film having a surface area at least
equal to the effective surface area of the tympanic
membrane, i.e., approximately 32 square mm in the
preferred embodiment. The elongated oval shape and
15 construction of the top speaker membrane 114 is also
disclosed in FIGS. 7A-7C. The top coil 116 is
rigidly affixed to the top speaker membrane 114 at
attachment edges 120. To make the speaker more
effective, compliance enhancing ripples 124 are
20 formed in the top speaker membrane 114. An
additional feature to make the speaker more effective
is the curved pleats 122 in the material of the top
speaker membrane. These pleats 122 are formed by
25 serrating the mold for the top speaker membranes, and
they enhance further the compliance of the top
speaker membrane 114. The top speaker coil 116
consists of 15 turns of oval shaped windings, and is
constructed of Number 48 AWG coated copper magnet
30 wire. The coating consists of a polymeric insulation
material and a secondary rubberized plastic
shape-holding material. The top spacer ring 144
holds the very outer edges of the top speaker
membrane 114 in place, and consists of metallic
material such as brass. The top armature of the
linear motor includes the top speaker membrane 114,
35 the top coil 116, and the top spacer ring 144.

1 The bottom speaker armature consists of the same
types of components and materials as does the top
speaker armature. In the case of the bottom
armature, there is a bottom speaker membrane 150, a
5 bottom coil 148, and a bottom spacer ring 154. The
materials of the bottom armature are virtually the
same as that of the top armature, however, certain
10 features may be varied to achieve a tweeter-type
speaker on the top (having enhanced treble response),
for example, and a woofer-type speaker on the bottom
(having enhanced bass response). Such features that
could be varied are those that affect the mass,
15 spring and damping characteristics of the armature,
such as the thickness of the speaker membranes, the
number of windings of the coil, and the size of the
magnet wire which makes up the coil, and also the
size and shape of the resonance cavities. The top
speaker resonance cavity is identified by the numeral
20 126, and the bottom speaker has a similar resonance
cavity identified by numeral 156, which is larger in
size (volume) for enhanced bass response in the
illustrated embodiment. The control gap 130 can be
used to vary the amount of air that can be exchanged
between two resonance cavities 126 and 156.

25 The linear motor 100 additionally consists of a
permanent magnet 136, and a magnet support piece
134. The permanent magnet of the preferred
embodiment consists of Neodium-Boron-Iron, or
30 Samarium Cobalt. Neodium-Boron-Iron can exert a
stronger magnetic field than Samarium-Cobalt,
however, Samarium-Cobalt will not rust.

35 The attachment edges 120 are node points for the
attachment of the coils to the speaker membranes.
This attachment is made by a rubber-based glue. The

1 speaker of the preferred embodiment, as described
above, is a moving coil circuit, whereas prior art
small hearing aid speakers generally have used
variable reluctance circuits, which generally have
5 given poor low frequency performance.

10 The microphone portion of the hearing aid 10 is
detailed in FIGS. 8A-8C and 9A-9C. The embodiment
illustrated in FIGS. 8A-8C uses an electret type
microphone. Forming an outer housing for the
15 microphone is the microphone cover 160. This cover
can be made of formed metal, such as aluminum, or
formed plastic. Just inside this cover is a first
spacer 162, which consists of a material which is
electrically nonconductive. This spacer is used to
20 maintain a gap between the microphone cover 160 and
the microphone diaphragm 164. The microphone
diaphragm consists of a permanently charged material,
such as metallized film or metallized polyester. On
25 the other side of the microphone diaphragm 164 is a
second spacer 166 which consists of a material which
is electrically nonconductive. The second spacer 166
maintains the quiescent gap between the microphone
diaphragm 164 and the plate 168.

25 The plate 168 consists of conductive metal, such
as nickel plated copper, or steel. The plate 168
rests on top of the mounting block 172, and also is
30 attached to the gate 176 of a field effect transistor
174. The mounting block 172 is formed of
electrically nonconductive material such as plastic.
The mounting block contains a provision 170 for
35 venting the gap which is inside the second spacer 166
and is between the microphone diagram 164 and the
plate 168. The field effect transistor 174 also has
a source 178 and a drain 180, and with a pair of

1 wires 182 attached, one to the gate and one to the source. Such electret microphone assemblies 184 are available in the prior art, such as one made by Panasonic having a part number WM-6A.

5 The microphone portion 14 illustrated in FIG. 8 also consists of two potentiometers and the on/off switch. The on/off switch consist of a conductive ring 190 which has a gap for the off portion of the ring. The turning of the microphone cover 160 actuates this on/off switch. The treble-bass filter control consists of a first potentiometer. The first potentiometer has a ring of resistance film media 194, which is not necessarily uniform, and a rotatable wiper 196. The first potentiometer media 194 is physically located and held in place by a nonconductive support 198. The rotatable wiper 196 is only engaged to rotate when the actuator 210 is depressed while being rotated. The actuator 210 is forced down when the microphone cover 160 is depressed. The support structure 192 is the overall housing base for maintaining the potentiometers in place while the microphone cover 160 is being depressed.

25 A second potentiometer controls the volume of the hearing aid. This second potentiometer consist of a ring of resistance film media 202, a rotatable wiper 204, and physical support which consists of a nonconductive support 206. The second potentiometer operates in the opposite sense as the first potentiometer in that its rotatable wiper 204 is actuated when the actuator 110 is not depressed. When the actuator 210 is not depressed, the spring 212 keeps tension on the rotatable wiper 204, and allows it to be rotated. To effectively communicate

1 electrical information to the control means, the
5 potentiometers and the on/off control must have
 conducting means such as wires attached to them. A
 pair of wires 200 runs to the first potentiometer, a
5 second pair of wires 208 runs to the second
 potentiometer, and a third pair of wires 214 runs to
 the on/off ring.

10 A piezo type microphone can alternatively be used
 rather than the electret type microphone. In the
 embodiment of FIG. 9, the microphone cover 220 is
 approximately the same size as the electret
 microphone cover 160. In this case, the microphone
 cover 220 must be made out of a material which is
15 electrically nonconductive. Just beneath the
 microphone cover 220 is the first spacer 222. This
 first spacer consists of an electrically conductive
 material, and is connected by a wire to the positive
 input of the microphone transducer amplifier. Below
20 (on the other side of) the first spacer 222 is the
 microphone diagram 224. This diagram consists of a
 material called Kynar, which is made by Pennwalt
 Corporation. On the other side of the microphone
 diagram 224 is a second spacer 226. This second
25 spacer is also made of an electrically conductive
 material, and is connected to the negative input of
 the transistor amplifier. The two spacers 222 and
 226 plus the microphone diagram 224 rest on the
 mounting block 228, and have two wires 232 attached
 to the two spacers (one wire per spacer). In the
30 embodiment of FIG.9, there is no field effect
 transistor and there is no plate. The remaining
 parts of the microphone portion of the embodiment of
 FIG. 9B are precisely the same as that shown in FIG.
35 8B.

1 One embodiment of the hearing aid can consist of
an optional accelerometer assembly 248. The
accelerometer is used to either enhance or attenuate
the conductive sound of the user's voice through the
user's bones into the cochlea of the ear. These
5 conductive sound waves travel through the temporal
bone which completely surrounds the inner ear, and
directly excite the mechanoneural sensory structures
within the inner ear. Conductive sound is present in
10 the normal ear, and its magnitude is normally
balanced with the air-borne portion of one's own
voice. However, such conductive sound, if existing
at a large magnitude, can be very distracting to the
user, in which case the accelerometer signal would be
15 attenuated. If it is absent in yet other users it
causes a distorted perception of the user's own
voice, and in which case the accelerometer signal
would be amplified. The accelerometer assembly 248
is built on the integrated circuit 50 in the main
20 body portion 16 of the device. The general layout of
the accelerometer is given in FIGS. 10A-10B, which
shows the substrate 240 and the seismic mass 242.
The substrate can be made of silicon, as used in the
substrate for integrated circuits. The seismic mass
25 242 would consist of a high density material, such as
copper. Sensing elements 244 are laid out on the
substrate 240 and consist of materials having
electrical characteristics which are sensitive to
strain. The nodes 246 are enlarged pads so as to
more easily make electrical connection to the
30 accelerometer assembly 248. The entire accelerometer
assembly 248 is built onto the integrated circuit 50,
and is physically isolated from the microphone and
the speaker. The accelerometer is, therefore, not
sensitive to air-borne sound waves, but only
35 bone-conducted sound waves.

1 It is obvious to one skilled in the art that the
accelerometer need not consist of a seismic mass 242
5 mounted on a strain gauged beam (substrate 240) as
described above. Other types of accelerometers
having similar size and construction could be used in
the alternative. Such other types of accelerometers
10 could consist of a mass 242 mounted on the movable
portion of a charged membrane 240, or a mass 242
mounted on a piezoelectric beam 240 (called a piezo
bimorphic). The major difference between the
15 different types of accelerometers is the material
used for the beam (the substrate 240), the nature of
the sensing elements 244 which are attached to the
beam 240, and the signal conditioning electronics
required among the various types.

20 The electrical schematic in block diagram form of
a stand alone hearing aid 10 is given in FIG. 11.
The control means 216 consists of three control
25 devices which are a part of the microphone portion
14. The three controls included in control means 216
are the on/off switch, the volume control
potentiometer, and the treble-bass filter
potentiometer. FIG. 11 uses an electret microphone
184, however, it should be recognized that any type
30 of miniature microphone could be used in this
application. The sound energy is transformed by the
microphone 184 into electrical signals which are
passed into the input microphone transducer amplifier
260. After initial amplification, the electrical
35 signal is then passed into a set of amplifiers which
act as a treble-bass filter and an intermediate gain
amplifier 262. This treble-bass filter and
intermediate gain amplifier 262 communicates with the
control means 216 so as to properly control the
hearing aid as per the user's wishes. Any automatic

1 gain control functions, whether linear or non-linear
in profile, are performed by the intermediate gain
5 amplifier 262. The output of the treble-bass filter
and the intermediate gain amplifier 262 is then
communicated to an output power amplifier 264. The
10 power amplifier 264 has as its output stage a class B
push-pull dual transistor output. By use of a dual
DC voltage power supply (supplied by two DC batteries
15 54), all of the amplifiers in the hearing aid can run
in a bipolar configuration, including the power
amplifier. By effective use of this bipolar DC power
supply, the power amplifier 264 can use push-pull
transistors on its final output stage, and eliminate
any typically large valued bypass capacitors that
would otherwise be required. The output signal of
15 the power amplifier 264 is then communicated to the
speaker, which consists of the linear motor 100.

20 The above amplifiers, including the output stage
power amplifier, are all located on the integrated
circuit 52. Some of the low-gain amplifier stages
use an operational amplifier such as the OP-90,
manufactured by Precision Monolithics. The OP-90 is
available on a semi-custom chip, or can be, of
25 course, placed on a custom analog chip.

30 Another embodiment of the invention uses a
hand-held transmitter to control the user's input
commands to the hearing aid. In FIG. 12 the
hand-held transmitter is designated 70, and consists
of an operator interface 266, a controller 268, and a
transmitter 72. The operator interface 266 could be
35 a key pad, a miniature keyboard, or even an existing
design TV remote controller, so that the user can hit
certain control keys to adjust the volume control of
the hearing aid, or to adjust the treble-base

1 filter. The controller 268 is typically a small
microprocessor unit which communicates through the
operator interface 266 and then passes commands in a
digital code signal format to the transmitter stage
5 72. The transmitter stage 72 can be of various types.

10 The various types of transmitters which can be
used are as follows: a radio frequency transmitter,
which would require some type of antenna built into
the hand-held unit, or an infrared transmitter, which
would require an infrared light emitting diode, or
possibly an ultrasonic transmitter means, which would
require some type of high frequency speaker output.
Whichever means of communication is utilized, it is
15 designated as 76 on FIG. 12.

20 The communication means 76 requires a
corresponding receiver 74, which is in the hearing
aid device 10. The receiver 74 converts the
communication signal to electrical signals, which are
then passed to the control means 270. The control
means 270 is similar in function to the previously
discussed control means 216 of FIG. 11, in that it
controls the treble-base filter and intermediate gain
25 amplifier 262 of the hearing aid 10. Also included
as part of the control signals is a local on/off
control function 190. The local on/off control 190
is needed to allow the user to completely turn off
electrical power in the hearing aid device 10. As in
the previous embodiment, the microphone 184 receives
30 sound energy and converts it to electrical energy,
which is passed to the microphone transducer
amplifier 260. The output of the transducer
amplifier 260 is communicated to the filter and gain
amplifier 262, which is now controlled by control
35 means 270, which utilizes the received information

1 from the receiver 74. The electrical signal is then sent to the power amplifier 264, and finally to the speaker element 100. To be effective, the receiver 74 requires an antenna 78.

5 Another embodiment of the hearing aid which uses a hand-held transmitter 70 is shown in FIG. 13. This embodiment also includes an accelerometer 248, to either add or subtract conductive sound information.

10 As before, the hand-held transmitter 70 consists of an operator interface 266, a controller 268, and a transmitter 72. The information is communicated by means 76 to the receiver 74 of the hearing aid device 10. Once the information is received by the receiver 74, it is communicated to the control means 270 which also communicates with the local on/off control 190.

15 The sound energy input is received at the microphone 184, and is converted into an electrical signal which is first amplified by the microphone transducer amplifier 260, then modified and amplified by the filter and intermediate gain amplifier 262, and is finally sent to a new amplifier element 278 which is a summation amplifier. The mechanical vibrations are sensed by the accelerometer 248, which converts the vibrations into an electrical signal. This electrical signal is received by the accelerometer transducer amplifier 272, which then outputs the signal to a gain amplifier stage 276. The control means 270 also communicates information to a volume control 274. Volume control 274 controls the gain of amplifier 276, however, the control means 270 also passes a signal to gain amplifier 276 which makes it possible for it to have reverse polarity. Polarity would be reversed in situations where the conductive sound picked up by the accelerometer 248 is to be attenuated. The output of the reversible polarity

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1 gain amplifier 276 is then communicated to the
summation amplifier 278. At this point the
accelerometer signal is either subtracted or added to
the microphone signal. The output of summation
5 amplifier 278 is then sent to the power amplifier 264
and then to the speaker element 100.

Another embodiment of the invention employs
10 signal processing techniques to greatly enhance the
performance of the invention for users with special
hearing problems. In FIG. 14 there is a portable
signal processing device 80, which can be either
carried by hand or worn on the clothing (such as
strapped to a belt) of the user. To adjust the
15 volume and treble-base controls, the user inputs
information through the operator interface 280, which
can be a key pad, which information is then
communicated to a controller 282. That information
is then communicated to the radio frequency
20 transmitter 82. This information would be in the
form of digital signals which are then transmitted
via communication means 90 to the receiver 86 of the
hearing aid 10. At the hearing aid 10, sound energy
is picked up by the microphone 184 and converted into
25 electrical signals which are passed to the microphone
transducer amplifier 260. The output of the
transducer amplifier 260 is sent to a second radio
frequency transmitter 88. This information is then
communicated via communication means 90 to a second
30 radio frequency receiver 84 which is located on the
signal processing device 80. This information is
communicated from the output of the receiver 84 to a
signal processing controller 284. The signal
processor 284 must work as nearly in real time as
35 possible, to accept the audio information from the
receiver 84 and then output the processed audio

1 information in the form of an electrical signal to
the radio frequency transmitter 82.

5 As is apparent to those skilled in the art, communication means 90 must be a full duplex means of
communicating radio frequency information both to and from each device, the hearing aid 10 and the signal processing device 80. Once the signal is transmitted from the radio frequency transmitter 82 it is
10 received by a radio frequency receiver 86 on the hearing aid device 10. The control portion of the received signal is a digital series of commands 286. These commands are communicated to the control means 270 which also communicates to a local on/off control 190. The audio portion of the received information which is received by radio frequency receiver 86 is an electrical signal 288. This audio signal is communicated to the filter and intermediate gain amplifier 262 which also communicates with the control means 270. The output of the filter and gain amplifier 262 is sent to the power amplifier 264 which outputs the signal to the speaker element 100.

25 An alternative embodiment of the invention which employs signal processing techniques is one that includes a self-contained enhanced signal processing controller within the hearing aid 10 itself. This embodiment is described in schematic form on FIG. 12, wherein the filter and intermediate gain amplifier 262 also contains the necessary signal processing controller to achieve the desired enhancement.

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35 Another embodiment of the invention can consist of a radio receiver 94 which can receive either commercial broadcast or local broadcast. As illustrated in FIG. 15, this embodiment uses a

1 hand-held transmitter 70, which consists of the
elements of the operator interface 266, the
controller 268, and the output transmitter 72.
Information from the transmitter 72 is communicated
5 by means 76 to a receiver 74 on the hearing aid
device 10. In this embodiment, the operator
interface 266 can also control the frequency to be
received at the hearing aid device 10 receiver 94.
That information is transmitted by transmitter 72 via
10 communication means 76 to the receiver 74. This
information is subsequently communicated to the
control means 270 and then to the tuner 290. The
control means 270 also communicates with a local
on/off control 190. Sound wave energy is received by
15 the microphone 184 and is converted to an electrical
signal which is communicated to the microphone
transducer amplifier 260. The output of this
transducer amplifier 260 is communicated to the
filter and intermediate gain amplifier 262, whose
20 output is then communicated to sound amplifier 278.

25 The hearing aid device 10 also receives radio
frequency information via its receiver 94. Radio
frequency receiver 94 can receive commercial
broadcasts, for example, in the AM and FM bands of
commercial communications, from a commercial
transmitter 92 via communication means 96. In the
case of a commercial transmitter, control means 270
30 transfers information to the tuner 290 which then
controls which radio station will be received by the
radio frequency receiver 94. The output of the
receiver 94 is sent to a gain amplifier 276 whose
gain is controlled by volume control 274 which
35 communicates to the control means 270. The output of
the gain amplifier 276 is then sent to the summation

1 amplifier 278 whose output consists of signals from
both the microphone and the radio receiver. The
output of the summation amplifier 278 is communicated
to the power amplifier 264 which then sends the
signal to the speaker element 100. If the user so
desires, radio frequency receiver 94 can receive a
5 local broadcast which might consist of a miniature
radio transmitter worn by the user which is
broadcasting music, for example, from a compact disc
10 player or from a cassette tape player. While such
local radio transmitters may not be in use today,
they are certainly foreseeable in the future,
particularly after the present invention becomes
common in the marketplace.

15 In summary, numerous benefits have been described
which result from employing the concepts of the
invention. The overall size, shape, and orientation
of the hearing apparatus provide a package which fits
20 deeply into the external auditory canal such that its
microphone is placed at the acoustic focus of the
concha, and its speaker is placed between the sigmoid
portion of the canal and the tympanic membrane. Such
placement of the speaker, along with sealing the air
25 inside the external auditory canal around the hearing
apparatus, achieves a closely-coupled system. The
hearing apparatus can be used as a stand-alone device
which includes all necessary signal-conditioning and
amplification electronic circuitry, as well as
enhanced signal processing, if so desired. The
30 hearing apparatus also can be used in conjunction
with a separate hand-held transmitter for controlling
various operational functions, a separate enhanced
signal processing device, if desired, or used in
communication with a radio transmitter.

1 The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Obvious modifications or variations are possible in light of the above teachings. The embodiment was chosen and described in order to best illustrate the principles of the invention and its practical application to thereby enable one of ordinary skill in the art to best utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto.

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I CLAIM:

1. An apparatus adapted for use in a human external auditory canal with a tympanic membrane at its innermost terminus, the external auditory canal having a cartilaginous part with an innermost section 5 of the cartilaginous part defining an S-shaped sigmoid portion, and a bony part that adjoins the sigmoid portion and extends to the tympanic membrane, the apparatus comprising:
 - 10 (a) means for receiving energy in the form of sound waves;
 - (b) means for converting the received energy into an electrical signal;
 - 15 (c) means for modifying said electrical signal; and
 - 20 (d) means for converting said modified electrical signal into energy in the form of air-borne sound waves, said converting means being located in proximity to the tympanic membrane and configured and dimensioned to fit within the external auditory canal in a location between the sigmoid portion and the 25 tympanic membrane.
2. An apparatus as recited in claim 1, wherein said means for converting sound wave energy into said electrical signal consists of a microphone.
3. An apparatus as recited in claim 2, wherein said microphone is an electret device.

4. An apparatus as recited in claim 2, wherein said microphone is a piezo electric device.

5. An apparatus as recited in claim 1, wherein said modifying means includes a variable-gain amplifier.

6. An apparatus as recited in claim 5, wherein said variable-gain amplifier include an automatic gain control circuit.

7. An apparatus as recited in claim 6, wherein said automatic gain control circuit has a non-linear profile.

8. An apparatus as recited in claim 1, wherein said modifying means includes a variable-gain amplifier stage and a treble-bass filter stage.

9. An apparatus as recited in claim 1, wherein said means for converting said modified electrical signal into said sound wave energy includes a speaker having an elongated shape, said speaker having a vibration surface with a length greater than its width so as to be insertable into the bony part of the external auditory canal past the sigmoid portion of the cartilaginous part while having a surface area substantially as large as the surface area of the tympanic membrane.

10. An apparatus as recited in claim 9, wherein said speaker includes a rigid housing.

11. An apparatus as recited in claim 9, wherein said speaker further includes a rigid housing having

5 a transverse cross-sectional geometry of a flattened tube with the housing having a longitudinal axis, the longitudinal axis of the housing being adapted for placement in substantially parallel relationship with the longitudinal axis of the external auditory canal, the transverse cross-sectional dimension of the housing being smaller than the lumen of the external
10 auditory canal.

12. An apparatus as recited in claim 9, wherein said speaker of elongated shape is mountable on a flexible articulation member.

13. An apparatus as recited in claim 12, wherein said flexible articulation member is rotatably flexible.

14. An apparatus as recited in claim 13, wherein said flexible articulation member is attached to an articulated joint.

5 15. An apparatus as recited in claim 9, wherein said speaker of elongated shape includes an electric motor having at least one reciprocially movable armature, said armature including of an oval-shaped coil and a speaker face membrane.

16. An apparatus as recited in claim 15, wherein said electric motor is linear.

17. An apparatus as recited in claim 15, wherein said electric motor includes at least one resonance cavity.

18. An apparatus as recited in claim 2, wherein

the apparatus is further adapted for use in a human external auditory canal in which the outer portion of the cartilaginous part defines a bowl-shaped concha having an acoustic focus, and the microphone is located substantially at the acoustic focus of the concha when the modified signal converting means is located between the sigmoid portion and the tympanic membrane.

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19. An apparatus as recited in claim 1, wherein said means for providing electric power consists of at least one battery.

20. An apparatus as recited in claim 1, further including means for preventing contamination of the modifying means and the modified signal converting means.

21. An apparatus as recited in claim 20, wherein said means for preventing contamination includes a disposable boot.

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22. An apparatus as recited in claim 21, wherein said disposable boot includes a resiliently deformable material portion which seals and isolates the received energy converting means from the modified signal converting means in the user's ear.

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23. A hearing aid, adapted for use in a human external auditory canal with a tympanic membrane at its innermost terminus, the external auditory canal having a cartilaginous part with an innermost section of the cartilaginous part defining an S-shaped sigmoid portion, a bony part that adjoins the sigmoid portion and extends to the tympanic membrane, the

outer section of the cartilaginous part defining a bowl-shaped concha having an acoustic focus, the
10 hearing aid comprising:

(a) a microphone, located at the acoustic focus of the concha, said microphone being operative to convert sound waves into a
15 microphone electrical signal;

(b) an accelerometer for producing an accelerometer electrical signal in response to and representative of the bone-conducted
20 portion of the user's speech;

(c) electronic circuit means for selectively modifying said microphone and accelerometer electrical signals and creating a joint
25 electrical signal;

(d) a speaker shaped and dimensioned to be located in the external auditory canal between the sigmoid portion of the cartilaginous part of the external auditory canal and the tympanic membrane, said speaker being operative to convert said joint
30 electrical signal into sound waves; and

35 (e) a self-contained D.C. power supply, providing electrical power to said electronic circuit means.

24. A hearing aid as recited in claim 23, wherein said accelerometer is constructed of a charged membrane having a first fixed portion and a second movable portion, and a mass mounted upon the second

5 movable portion.

5 --- 25. A hearing aid as recited in claim 23, wherein said accelerometer is constructed of a piezoelectric beam having a first fixed portion and a movable second portion, and a mass mounted upon the second movable portion.

5 26. A hearing aid as recited in claim 23, wherein said accelerometer is constructed of a strain gauged beam having a first fixed portion and a movable second portion, and a mass mounted upon the second movable portion.

27. A hearing aid as recited in claim 23, wherein said accelerometer is formed as an integrated unit on a substrate.

28. A hearing aid as recited in claim 23, further comprising an ON-OFF switch.

29. A hearing aid as recited in claim 28, wherein said ON-OFF switch functions in a rotatable manner.

30. A hearing aid as recited in claim 23, wherein said electronic circuit means includes a signal conditioning amplifier having an FET input stage.

31. A hearing aid as recited in claim 23, wherein said electronic circuit means includes a signal conditioning amplifier having a bipolar input stage.

32. A hearing aid as recited in claim 23, wherein said electronic circuit means includes an input stage, a gainshaping filter network stage, and an output driving stage.

33. A hearing aid as recited in claim 23, further comprising means for receiving and demodulating control signals, said electronic circuit means being responsive to said demodulated control signals.

34. A hearing aid as recited in claim 33, further comprising:

5 (i) a portable transmitter which communicates with said receiving and demodulating means, said portable transmitter including an operator interface for entering gain and filtering parameters of the microphone and accelerometer electrical signals;

10 (ii) a controller for communicating with said operator interface and creating a command electrical signal;

15 (iii) an output stage for modulating said command electrical signal and creating a control signal for said receiving and demodulating means, said control signal being transmitted via carrier wave to said receiving and demodulating means; and

20 (iv) a self-contained D.C. power supply, providing electrical power to said operator interface and controller, and to said output transmitter stage.

25 35. A hearing aid, comprising:

5 (a) a microphone for receiving and converting sound waves into a representative electrical signal;

(b) a signal processing circuit;

10 (c) means for communicating said representative electrical signal to said signal processing circuit, said signal processing circuit being operative to enhance the representative electrical signal and create a processed signal;

15 (d) a radio transmitter, said transmitter modulating the processed signal and creating a modulated processed signal, the transmitter outputting the modulated processed signal via carrier wave;

20 (e) a radio receiver adapted for positioning within the human ear for receiving and demodulating the modulated processed signal;

25 (f) signal conditioning means for conditioning said demodulated processed signal; and

30 (g) a speaker responsive to said conditioned processed signal, said speaker converting the conditioned processed signal into sound waves.

36. A hearing aid as recited in claim 35, wherein said microphone is adapted for positioning in the human ear, and said communicating means includes a second radio transmitter adapted for positioning in the human ear and a second radio receiver adapted for positioning external to the human ear, the signal processing circuit being responsive to said second radio receiver.

37. A hearing aid comprising:

5 a) a microphone for receiving and converting sound waves into a representative microphone electrical signal;

10 b) an accelerometer adapted for placement proximal to a user's ear, the accelerometer being responsive to a user's bone-conducted speech for creating a representative accelerometer electrical signal;

15 c) signal processing means for creating a processed signal which is dependent upon both the microphone and accelerometer electrical signals, at least a portion of the signal processing means being adapted for placement distal to the user's ear;

20 d) a radio transmitter, said transmitter modulating the processed signal and creating a modulated processed signal, the transmitter outputting the modulated processed signal via carrier wave;

25 e) a radio receiver adapted for positioning proximal to the user's ear for receiving and demodulating the modulated processed signal;

30 f) signal conditioning means for conditioning said demodulated processed signal; and

35 g) a speaker responsive to said conditioned processed signal, said speaker converting the conditioned processed signal into sound waves.

38. A hearing aid as recited in claim 37, wherein the signal processing means includes means for modifying the microphone and accelerometer electrical signals and creating a joint electrical signal, a 5 second radio transmitter for modulating and transmitting the joint electrical signal; a second radio receiver for receiving and demodulating the joint electrical signal; and means for enhancing the demodulated joint electrical signal.

39. A hearing aid as recited in claim 37, wherein the signal processing means includes a second radio transmitter for modulating and transmitting the accelerometer electrical signal, a second radio receiver for receiving and demodulating the accelerometer electrical signal, means for combining the accelerometer electrical signal with the microphone electrical signal to form a joint signal; and means for enhancing the joint signal. 5

40. A hearing aid comprising:

(a) a microphone, said microphone being operative to convert sound waves into a 5 microphone electrical signal;

(b) an accelerometer for producing an accelerometer electrical signal in response to and representative of the bone-conducted 10 portion of the user's speech;

(c) electronic circuit means for selectively modifying said microphone and accelerometer electrical signals and creating a joint 15 electrical signal;

(d) a speaker, said speaker being operative to convert said joint electrical signal into sound waves; and

20 (e) a self-contained D.C. power supply, providing electrical power to said electronic circuit means.

41. A hearing aid as recited in claim 40, wherein said accelerometer is constructed of a charged membrane having a first fixed portion and a second movable portion, and a mass mounted upon the second
5 movable portion.

42. A hearing aid as recited in claim 40, wherein said accelerometer is constructed of a piezoelectric beam having a first fixed portion and a movable second portion, and a mass mounted upon the second
5 movable portion.

43. A hearing aid as recited in claim 40, wherein said accelerometer is constructed of a strain gauged beam having a first fixed portion and a movable second portion, and a mass mounted upon the second
5 movable portion.

44. A hearing aid as recited in claim 40, wherein said accelerometer is formed as an integrated unit on a substrate.

45. A hearing aid as recited in claim 40, further comprising means for receiving and demodulating control signals, said electronic circuit means being responsive to said demodulated control signals.

46. An apparatus adapted for use in a human external auditory canal with a tympanic membrane at its innermost terminus, the external auditory canal having a cartilaginous part with an innermost section 5 of the cartilaginous part defining an S-shaped sigmoid portion, and a bony part that adjoins the sigmoid portion and extends to the tympanic membrane, the apparatus comprising:

10 (a) means for receiving radio-frequency energy;

(b) means for converting the received energy into an electrical signal;

15 (c) means for modifying said electrical signal; and

(d) means for converting said modified 20 electrical signal into energy in the form of air-borne sound waves, said converting means being located in proximity to the tympanic membrane and configured and dimensioned to fit within the external auditory canal in a 25 location between the sigmoid portion and the tympanic membrane.

AMENDED CLAIMS

[received by the International Bureau
on 25 May 1992 (25.05.92);
original claims 1,2,12,15,17 and 20 amended;
other claims unchanged (5 pages)]

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1. An apparatus adapted for use in a human external auditory canal with substantially non-compliant side walls and a compliant tympanic membrane at its innermost terminus, the external auditory canal having a cartilaginous part with an innermost section of the cartilaginous part forming an S-shaped sigmoid portion, and a bony portion that extends to the tympanic membrane, the apparatus comprising:

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(a) means for receiving energy in the form of sound waves and converting the received energy into an electrical signal;

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(b) means for modifying said electrical signal;

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(c) means for converting said modified electrical signal into energy in the form of air-borne sound waves, said converting means including an active compliance surface having a functional area comparable to that of the tympanic membrane for creating said airborne sound waves, said compliant surface being located in proximity to the tympanic membrane and being configured and dimensioned to fit at least partially within the external auditory canal in a location between the sigmoid portion and the tympanic membrane; and

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(d) means for acoustically isolating the inner and external portions of the auditory canal along with the substantially non-compliant side walls and such that the compliance surface of the converting means and the compliant tympanic membrane along with the non-compliant walls of the auditory canal form a closed cavity.

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2. An apparatus as recited in claim 1, wherein said means for receiving energy and converting the received energy into an electrical signal includes a microphone.

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3. An apparatus as recited in claim 2, wherein said microphone is an electret device.

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1 a transverse cross-sectional geometry of a flattened tube with the housing having a longitudinal axis, the longitudinal axis of the housing being adapted for placement in substantially parallel relationship with the longitudinal axis of the external auditory canal, the transverse cross-sectional dimension of the housing being smaller than the lumen of the external auditory canal.

10 12. An apparatus as recited in claim 1, further including a speaker having an electric motor and at least one reciprocably moveable armature, said armature including a coil and a speaker face membrane, said speaker being rotatably mounted on a 15 articulation and member.

13. An apparatus as recited in claim 12, wherein said flexible articulation member is rotatably flexible.

20 14. An apparatus as recited in claim 13, wherein said flexible articulation member is attached to an articulated joint.

25 15. An apparatus as recited in claim 1, further including a speaker having an electric motor and at least one reciprocably movable armature, said armature including a coil and a speaker face membrane.

30 16. An apparatus as recited in claim 15, wherein said electric motor is linear.

35 17. An apparatus as recited in claim 15, wherein said electric motor includes at least one resonance cavity on the opposite side of the compliance surface

1 of the converting means relative to the tympanic
membrane.

5 18. An apparatus as recited in claim 2, wherein

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1 the apparatus is further adapted for use in a human external auditory canal in which the outer portion of the cartilaginous part defines a bowl-shaped concha having an acoustic focus, and the microphone is located substantially at the acoustic focus of the concha when the modified signal converting means is located between the sigmoid portion and the tympanic membrane.

10 19. An apparatus as recited in claim 1, wherein said means for providing electric power consists of at least one battery.

15 20. An apparatus as recited in claim 1, further including means for preventing biological contamination of the modifying means and the modified signal converting means.

20 21. An apparatus as recited in claim 20, wherein said means for preventing contamination includes a disposable boot.

25 22. An apparatus as recited in claim 21, wherein said disposable boot includes a resiliently deformable material portion which seals and isolates the received energy converting means from the modified signal converting means in the user's ear.

30 23. A hearing aid, adapted for use in a human external auditory canal with a tympanic membrane at its innermost terminus, the external auditory canal having a cartilaginous part with an innermost section of the cartilaginous part defining an S-shaped sigmoid portion, a bony part that adjoins the sigmoid portion and extends to the tympanic membrane, the

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STATEMENT UNDER ARTICLE 19

5 Claims 1, 2, 12, 15 and 17 have been amended to add limitations not present in these claims as originally filed, and to more clearly distinguish over the prior art of record. No claims have been cancelled.

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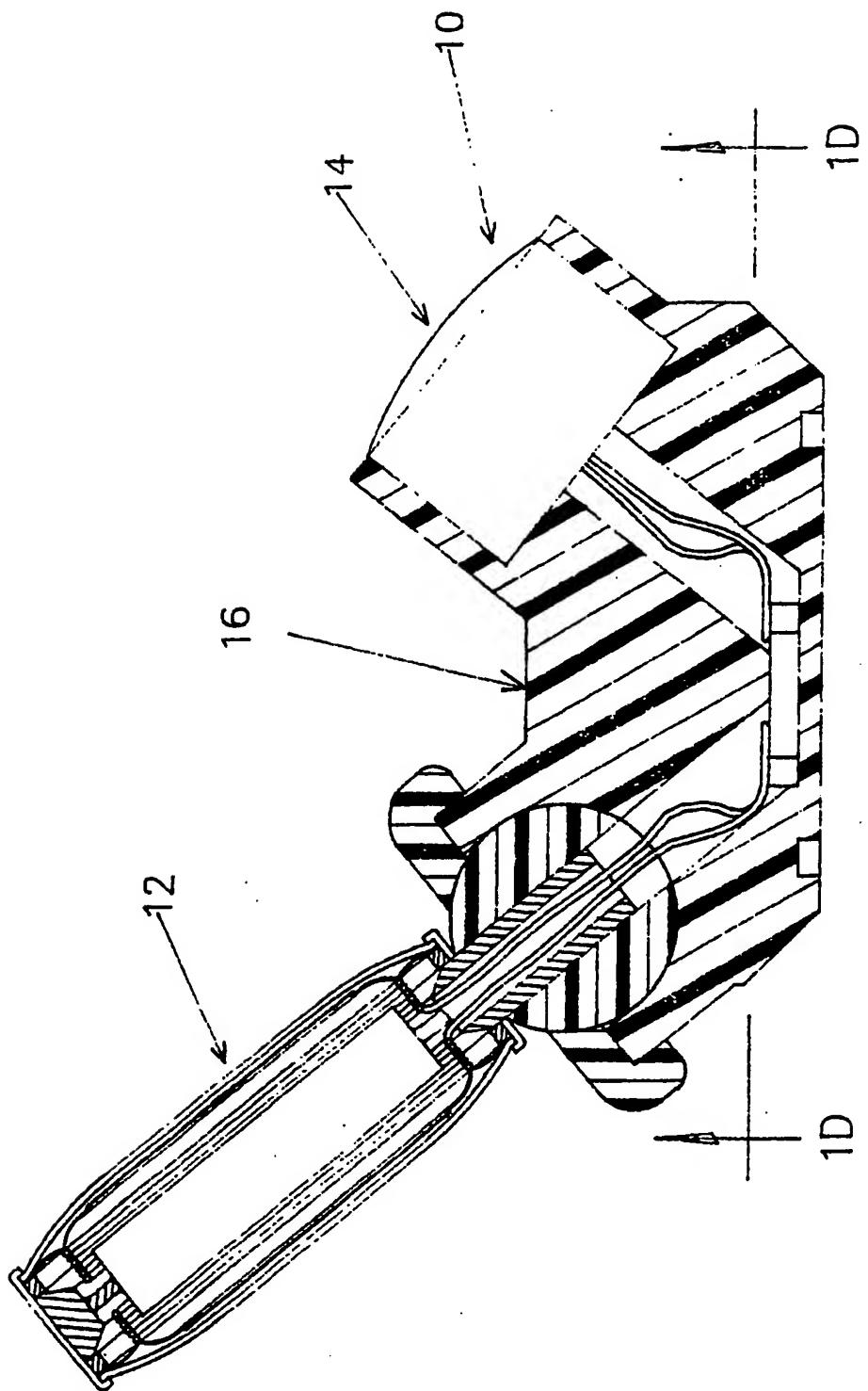


FIG. 1A

2 / 21

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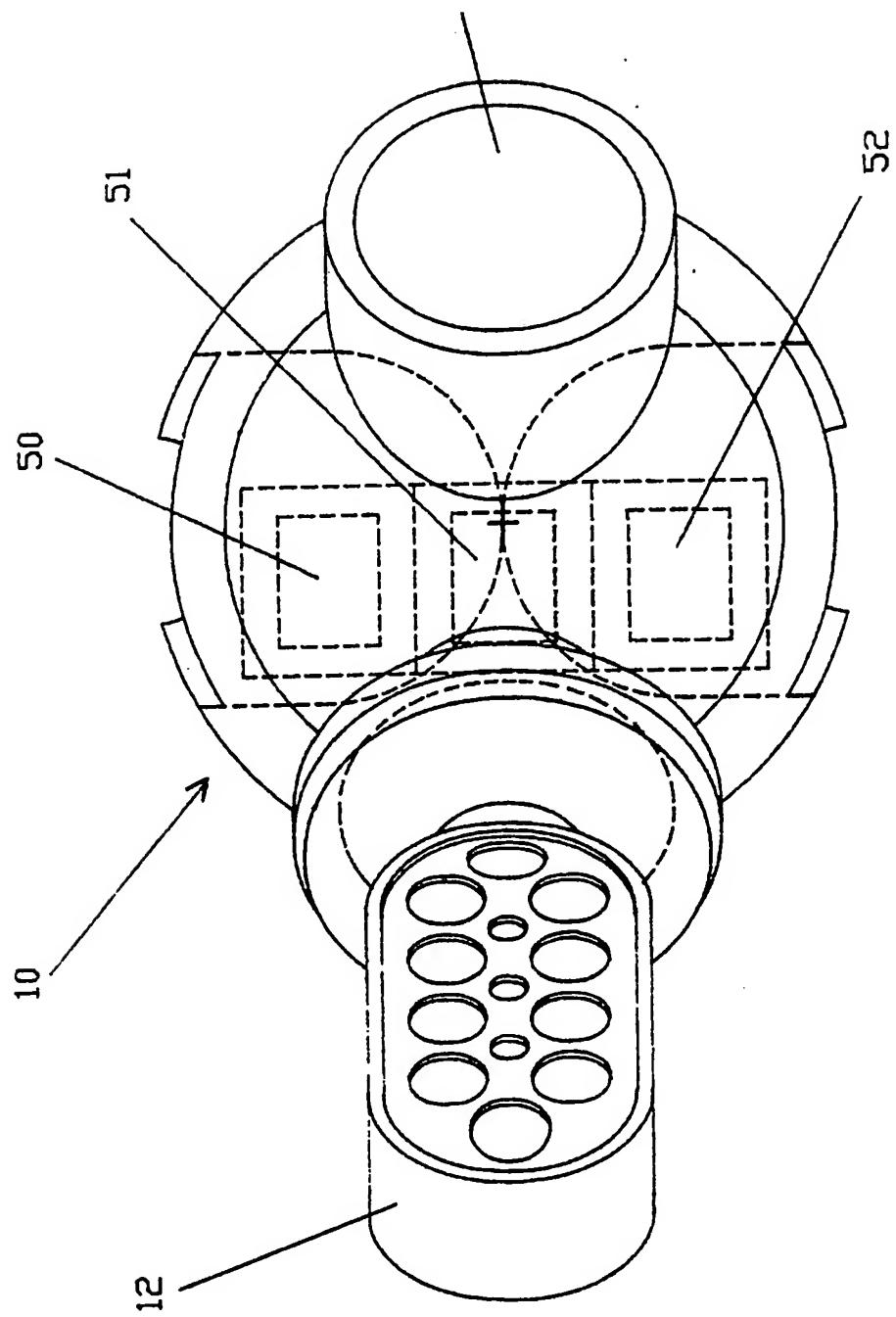


FIG. 1B

3 / 2 1

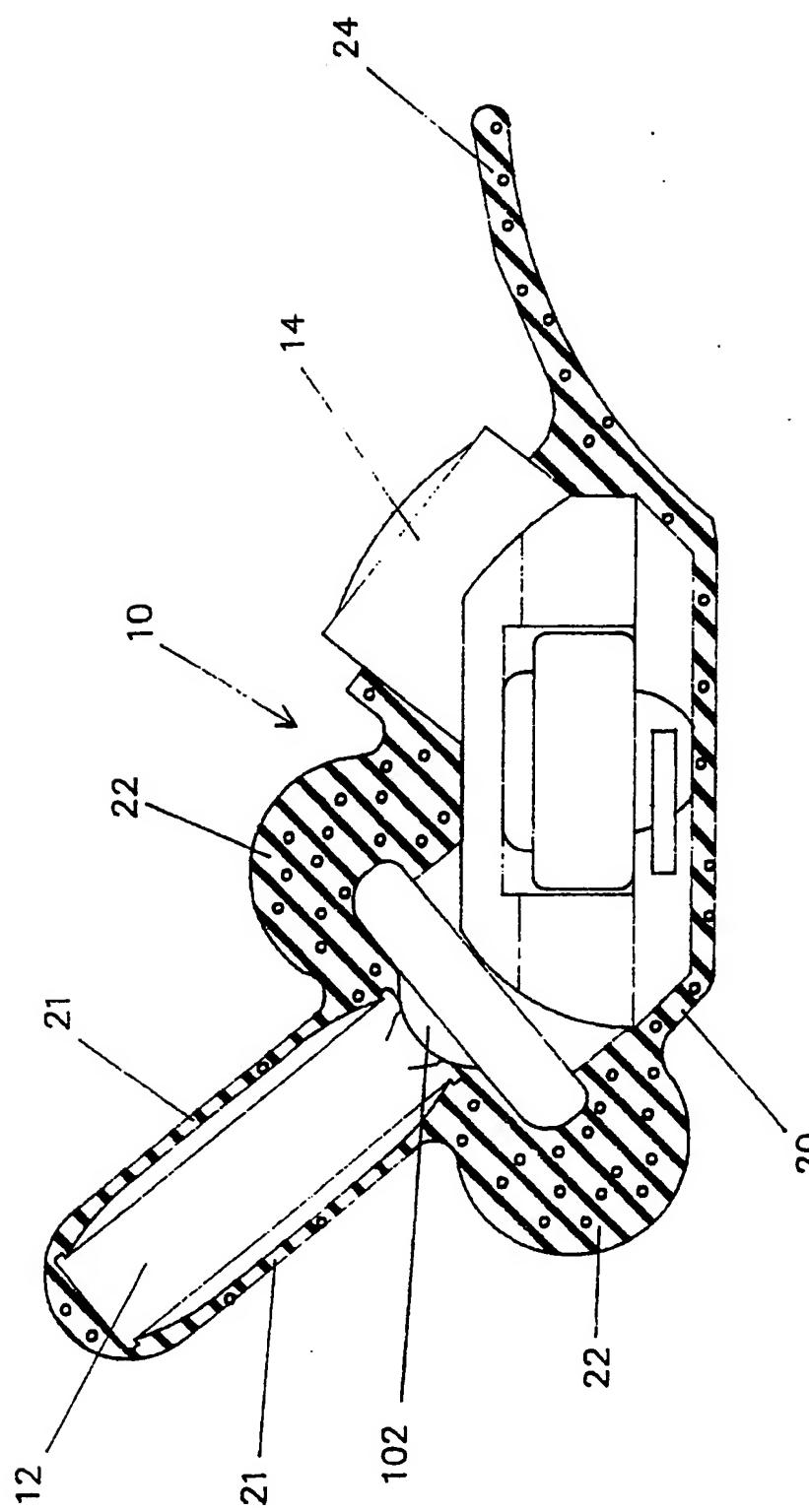


FIG. 1C

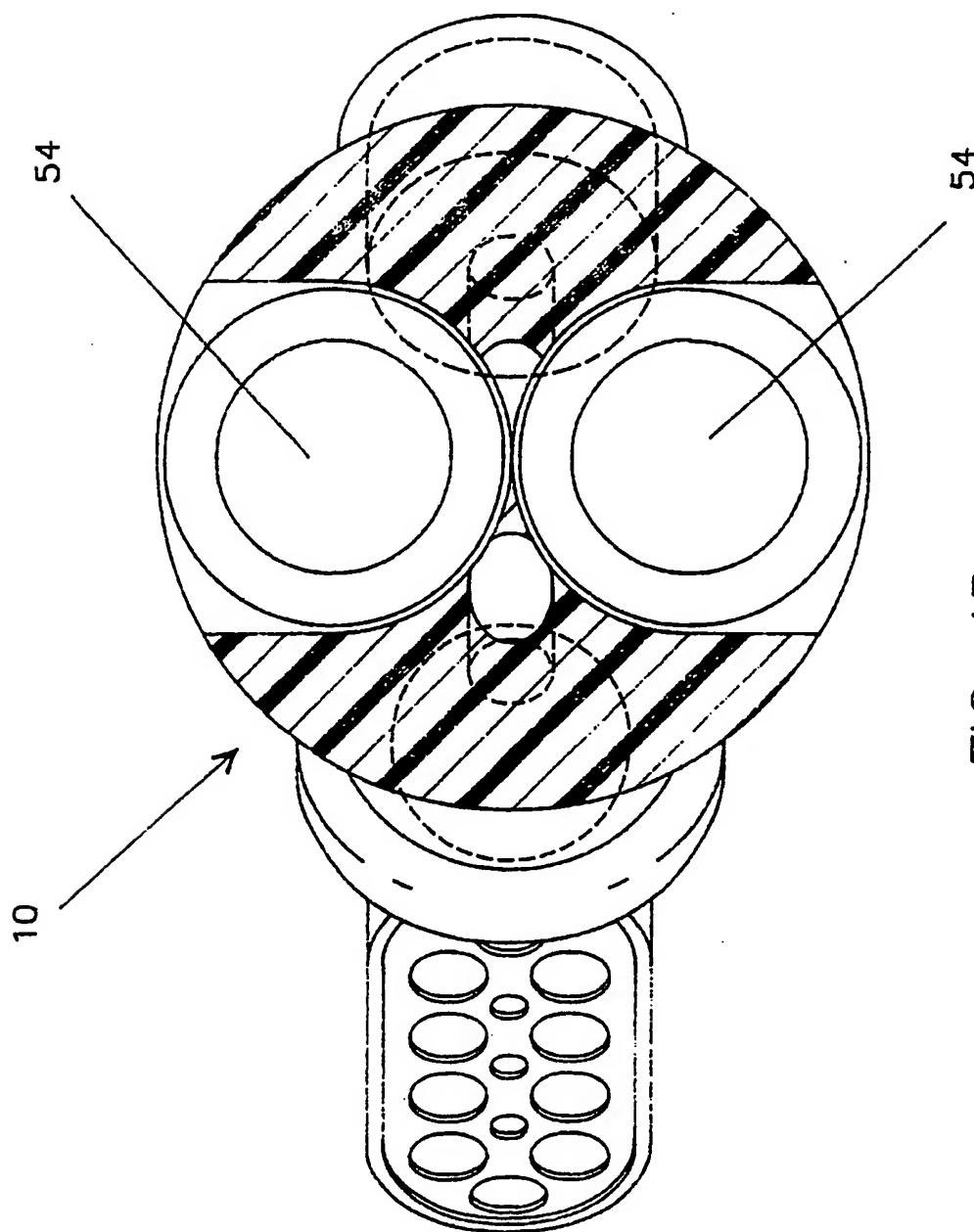
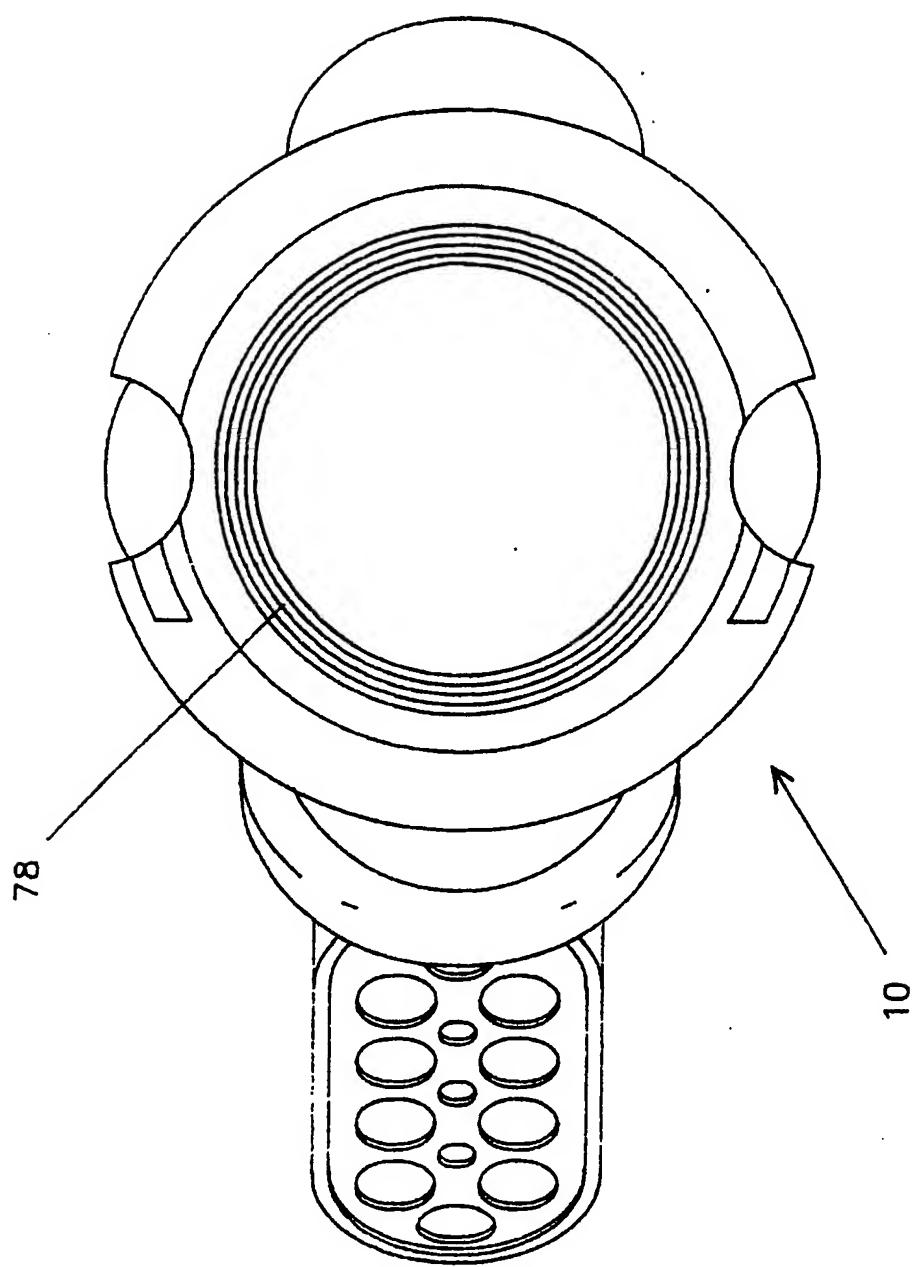


FIG. 1D



6 / 21

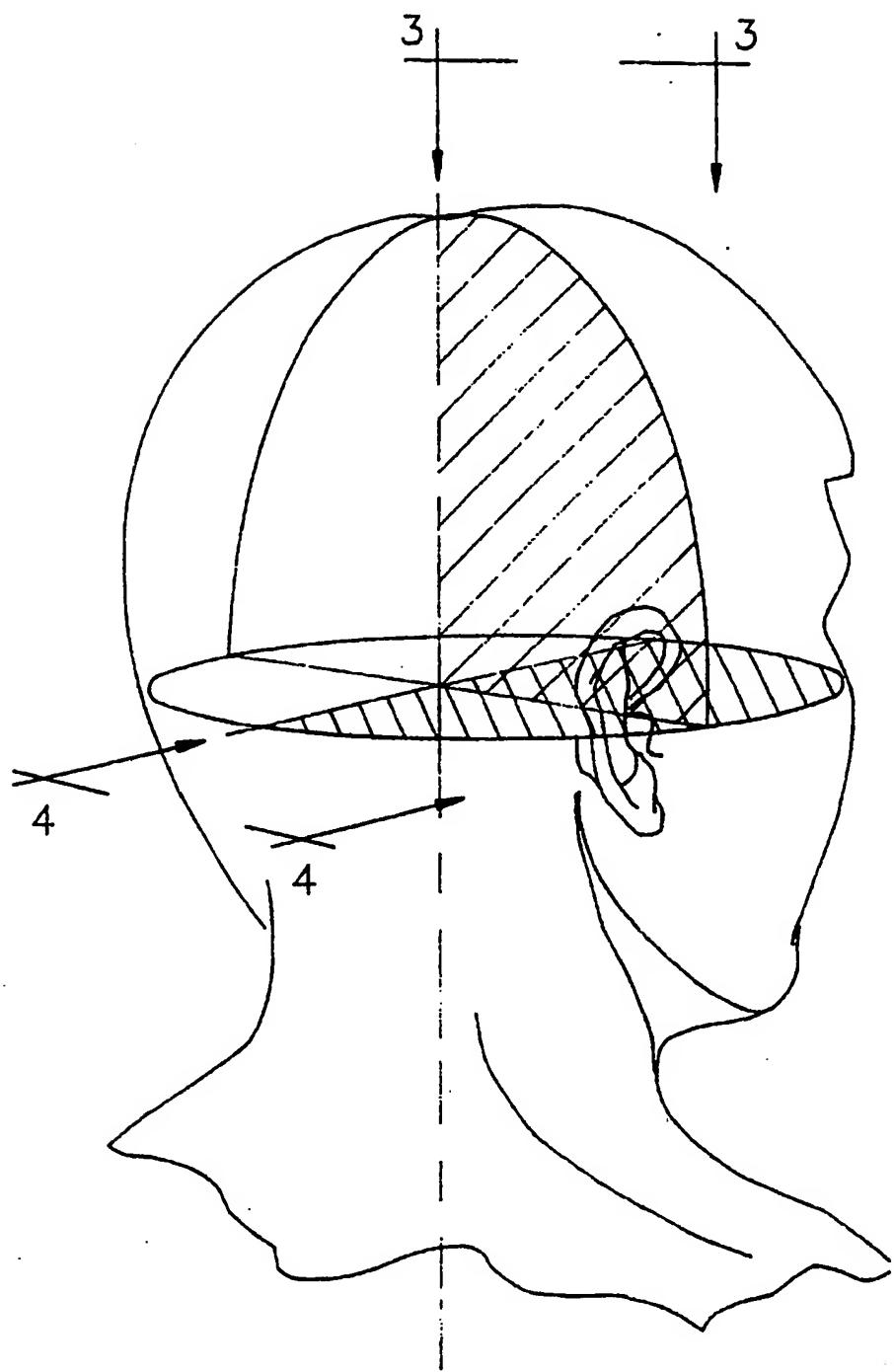
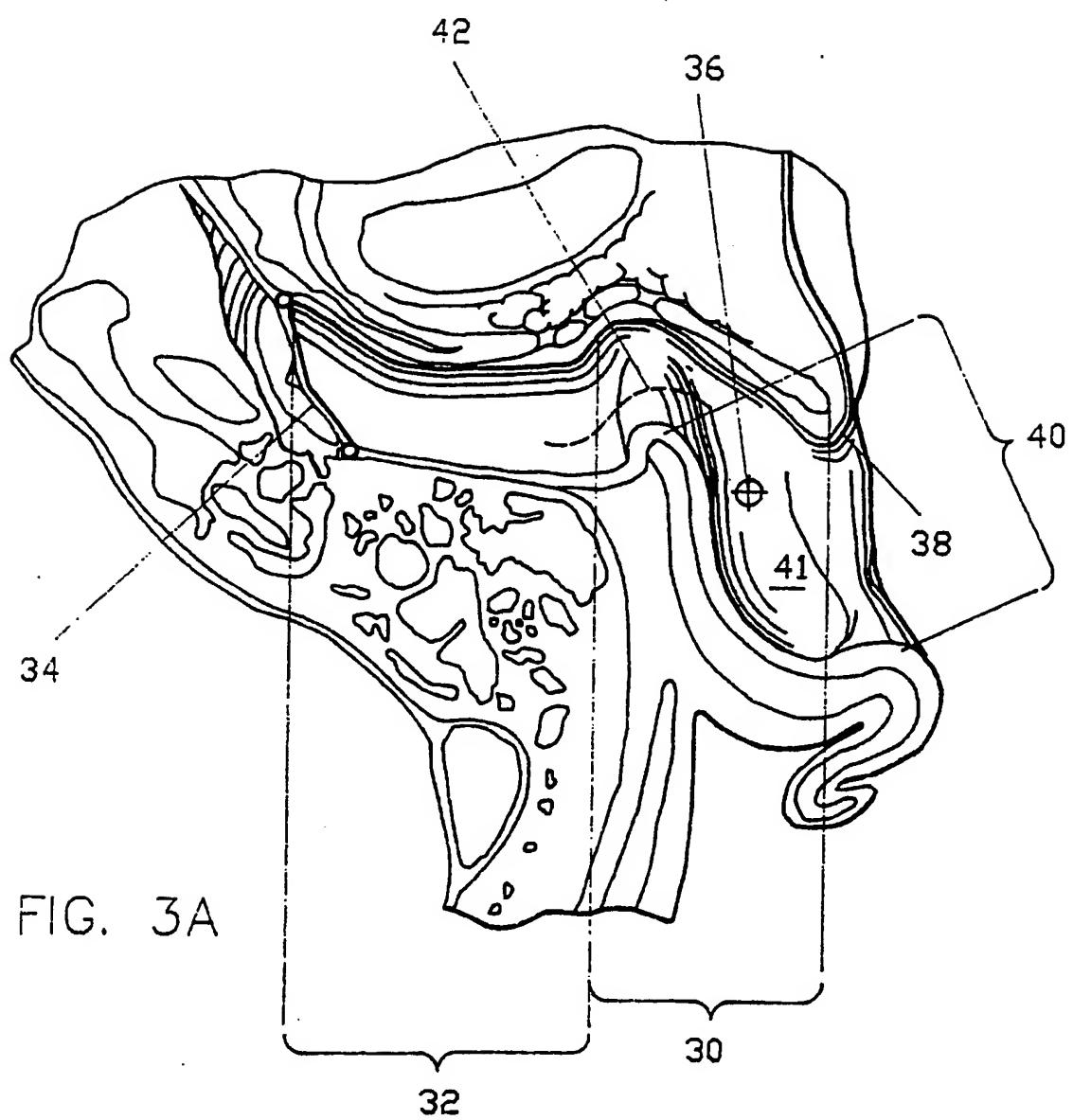


FIG. 2

7 / 21



8 / 21

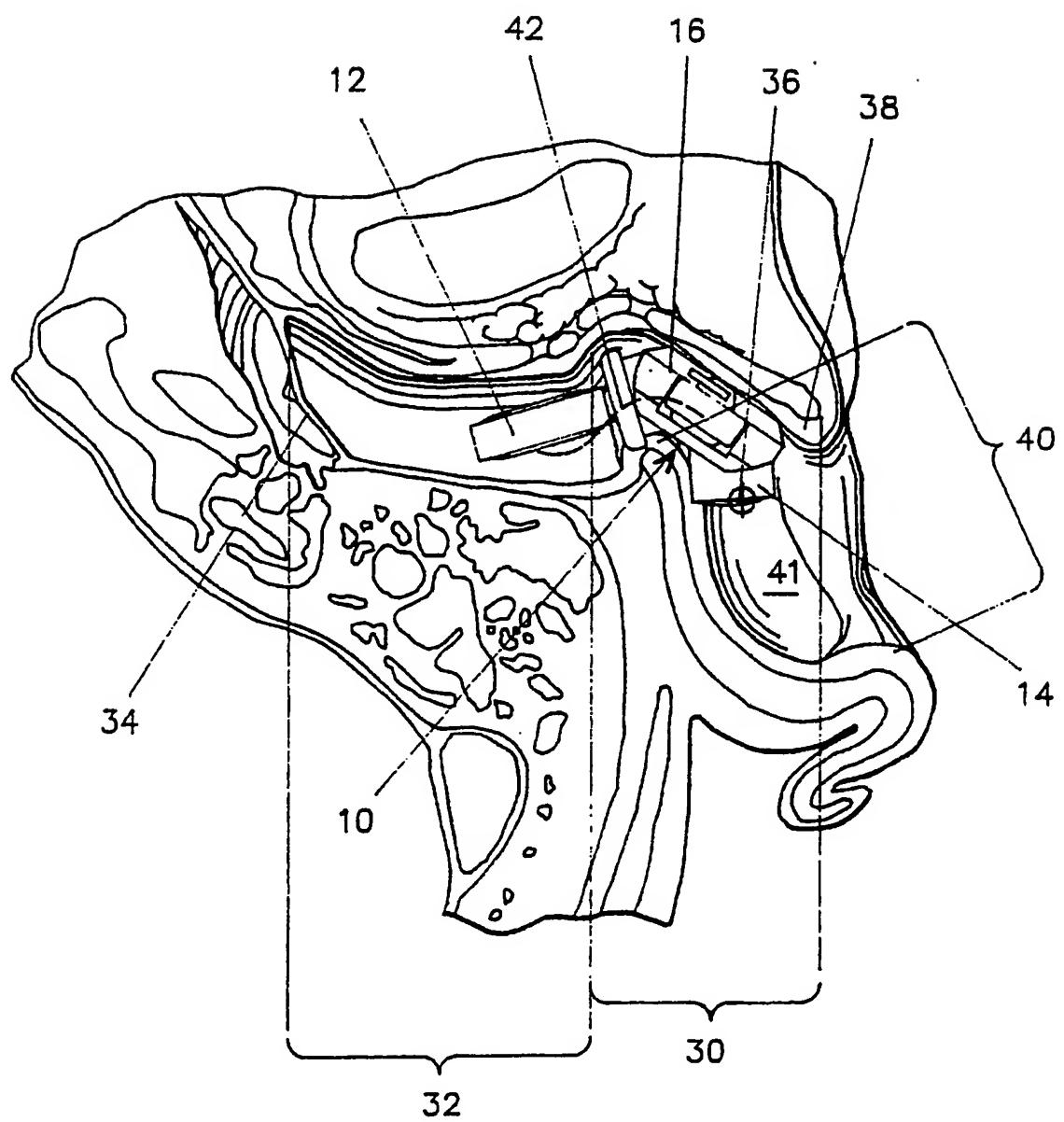
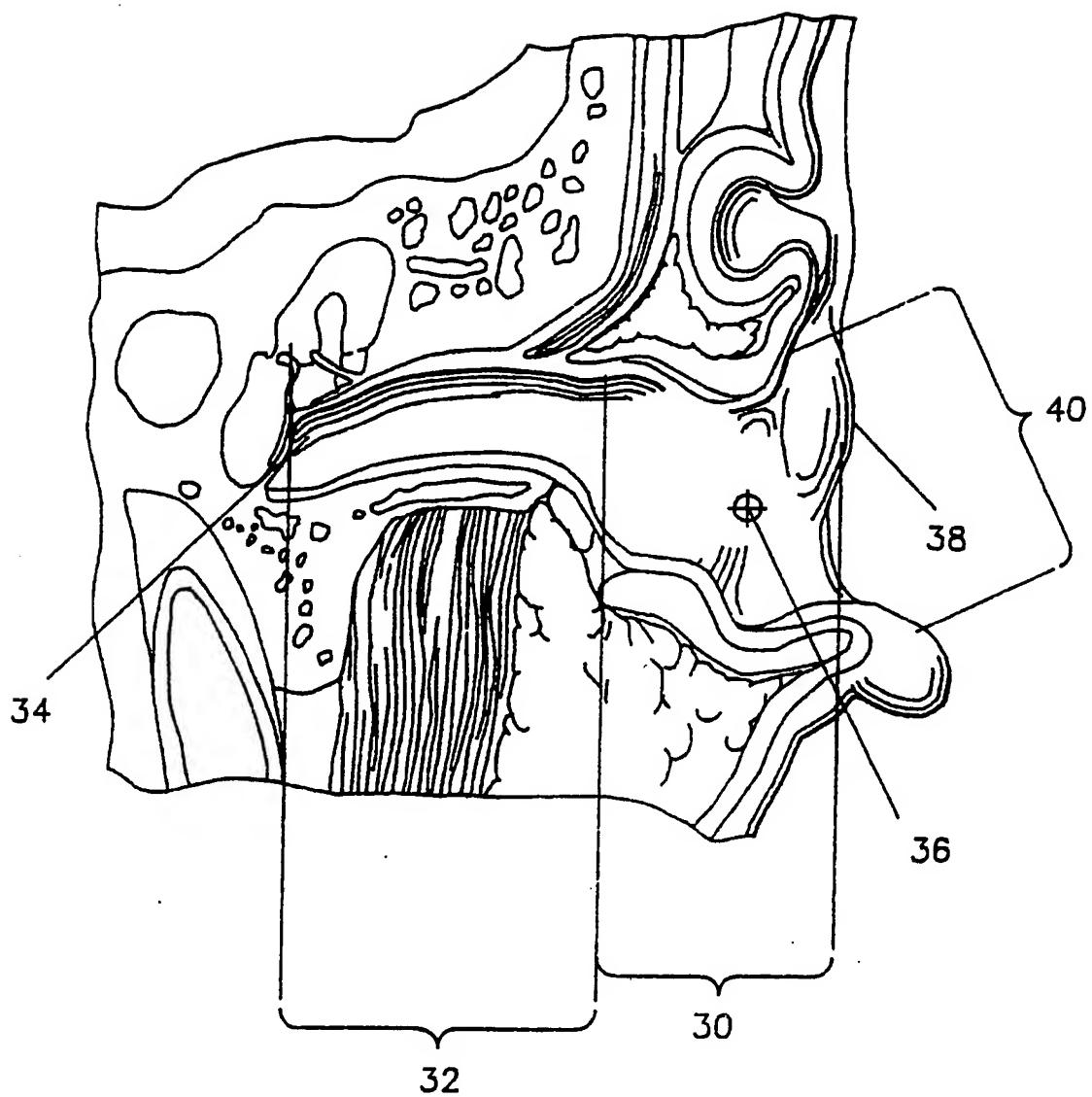


FIG. 3B

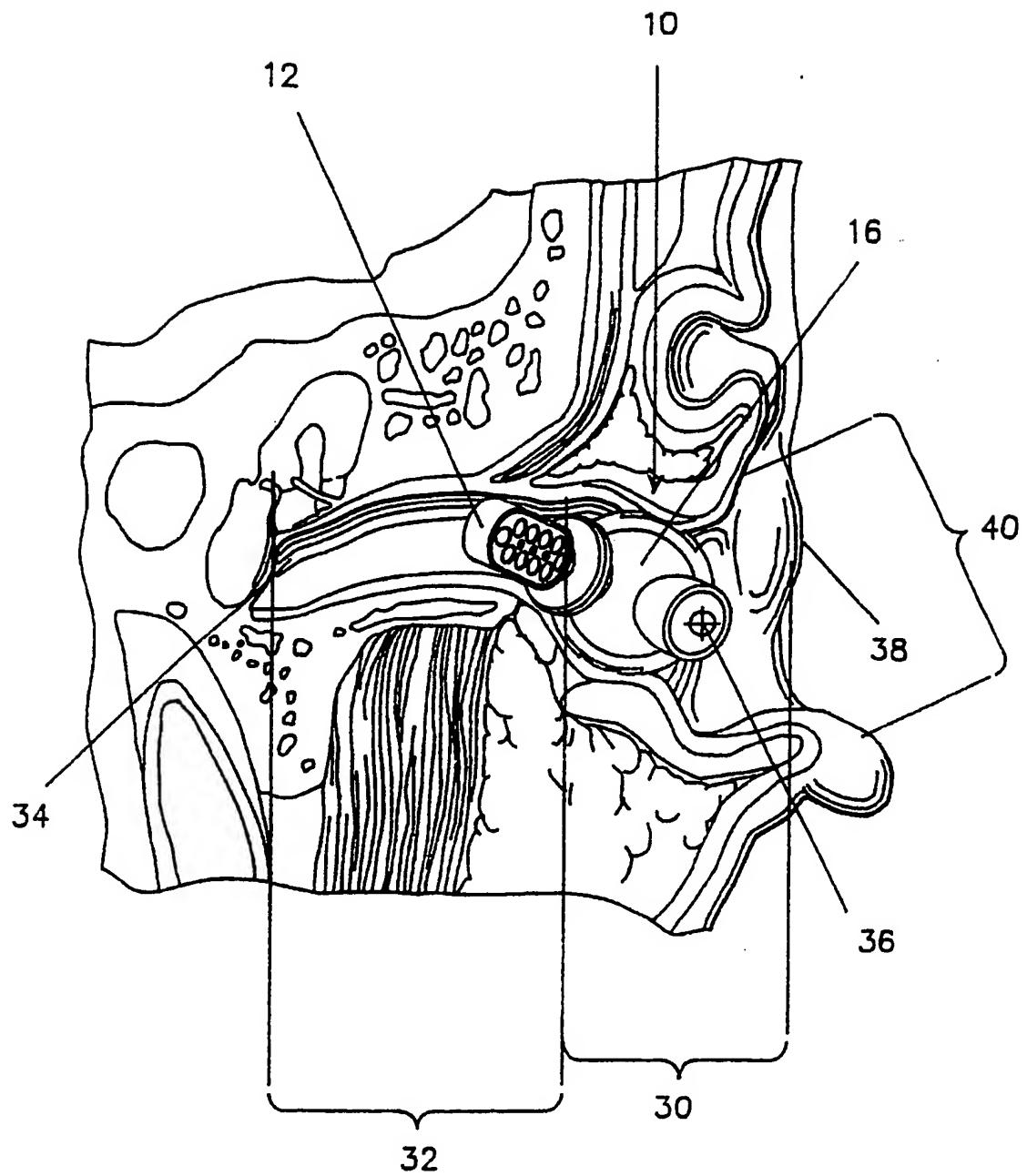
9 / 21

FIG. 4A



10 / 21

FIG. 4B



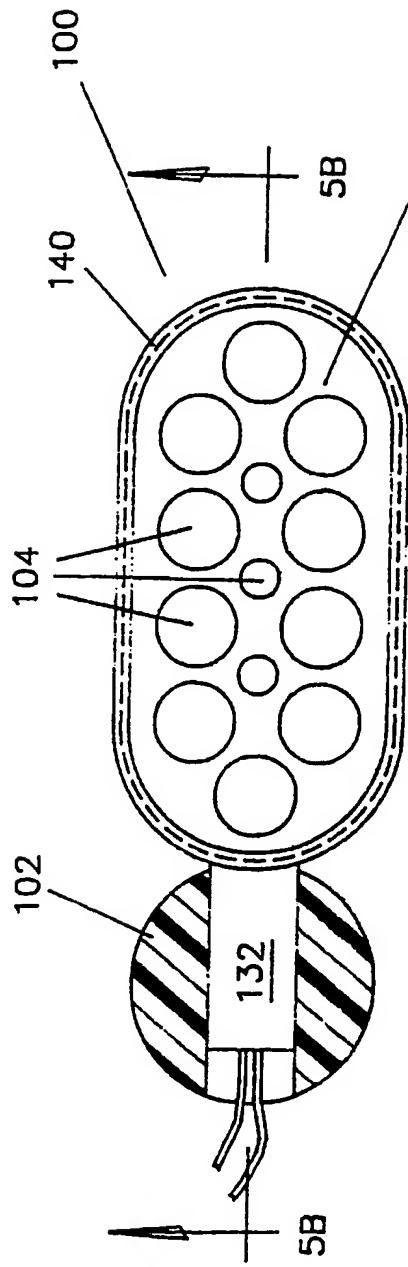


FIG. 5A

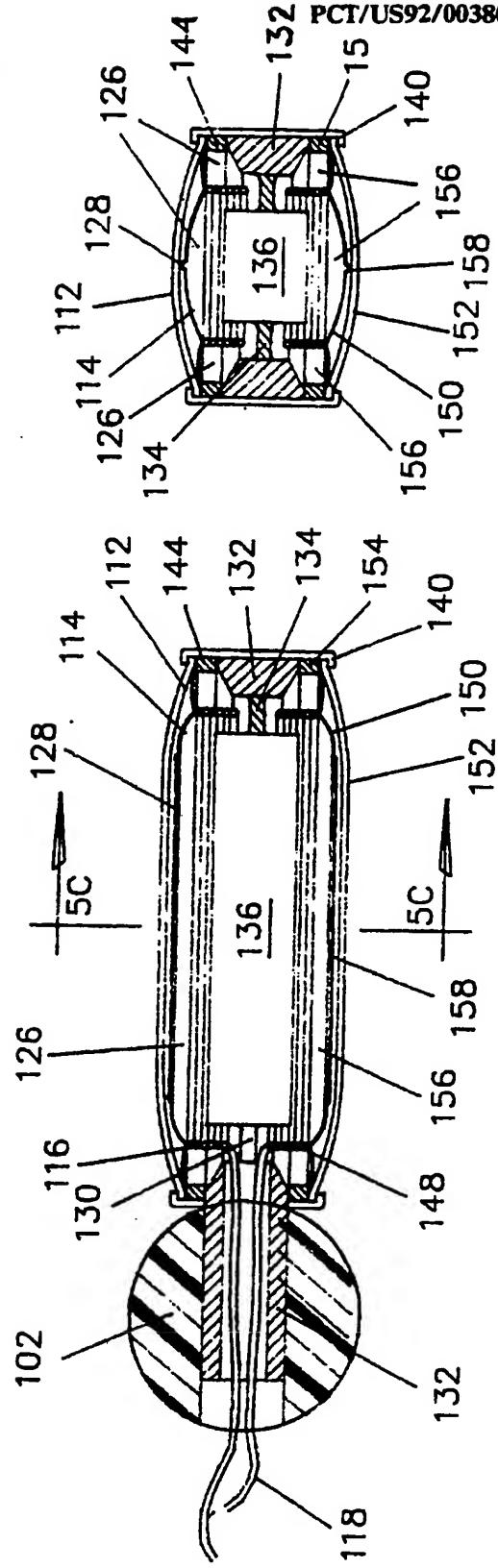


FIG. 5B
FIG. 5C

12 / 21

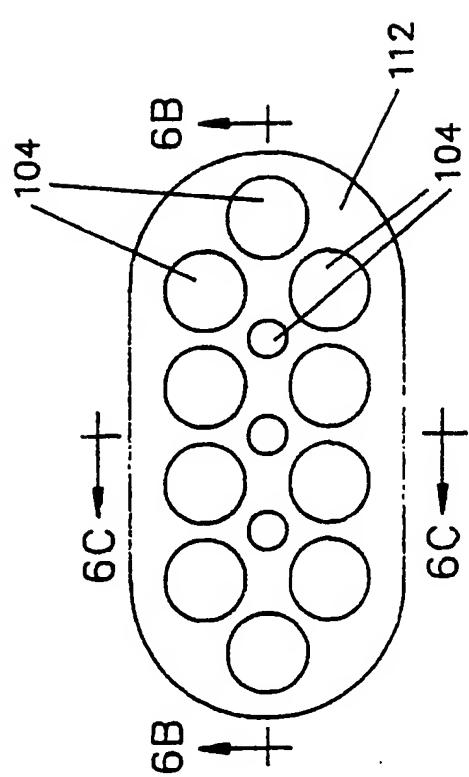


FIG. 6A

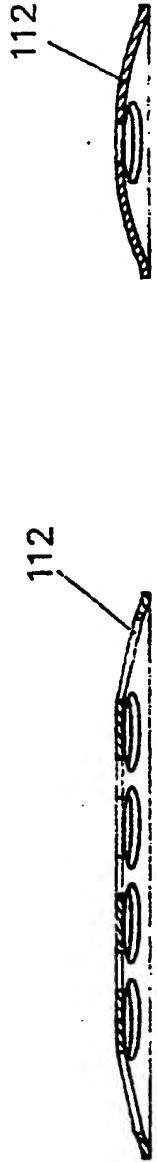


FIG. 6B

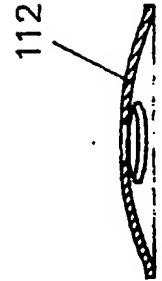


FIG. 6C

13 / 21

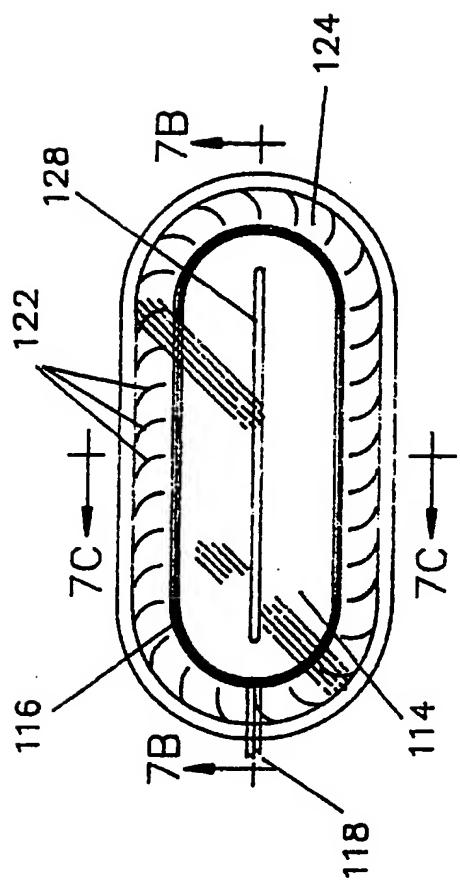


FIG. 7A

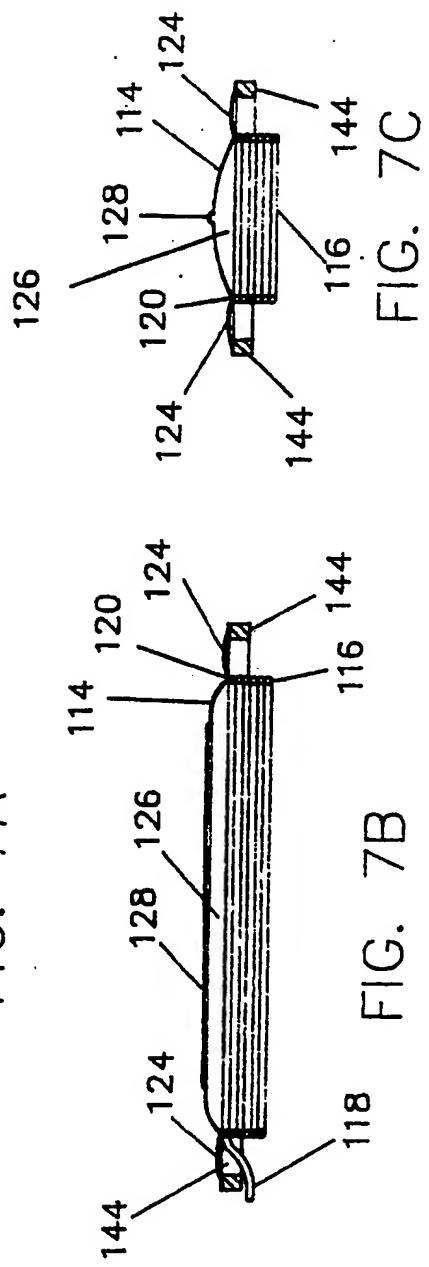


FIG. 7B

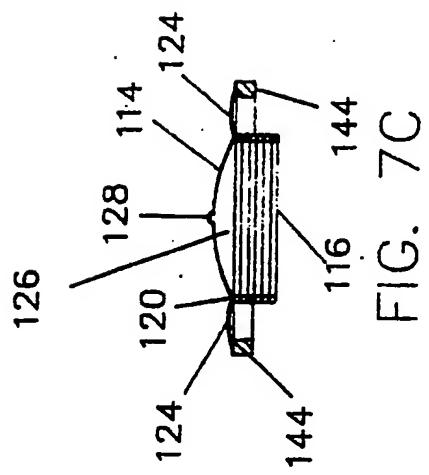


FIG. 7C

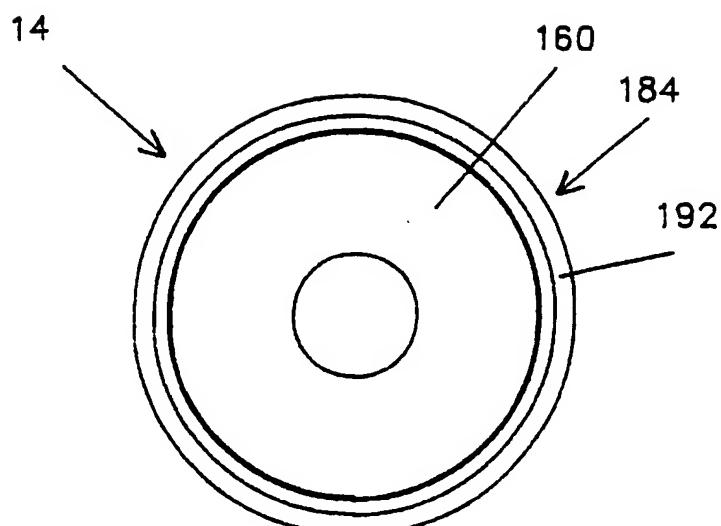


FIG. 8A

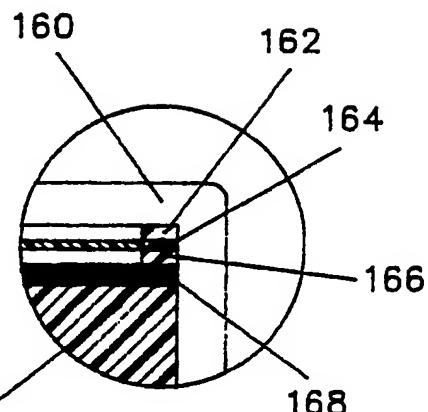


FIG. 8C

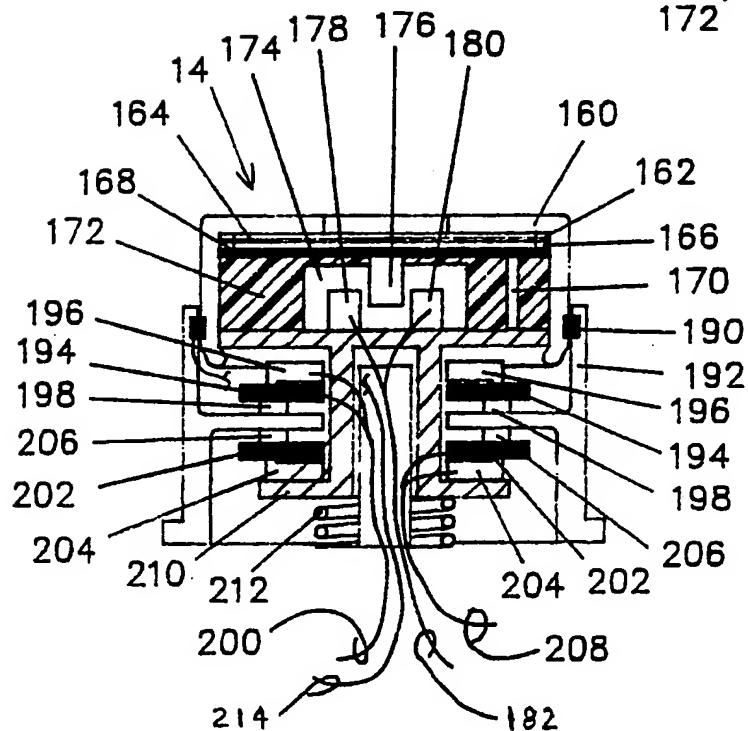


FIG. 8B

15 / 21

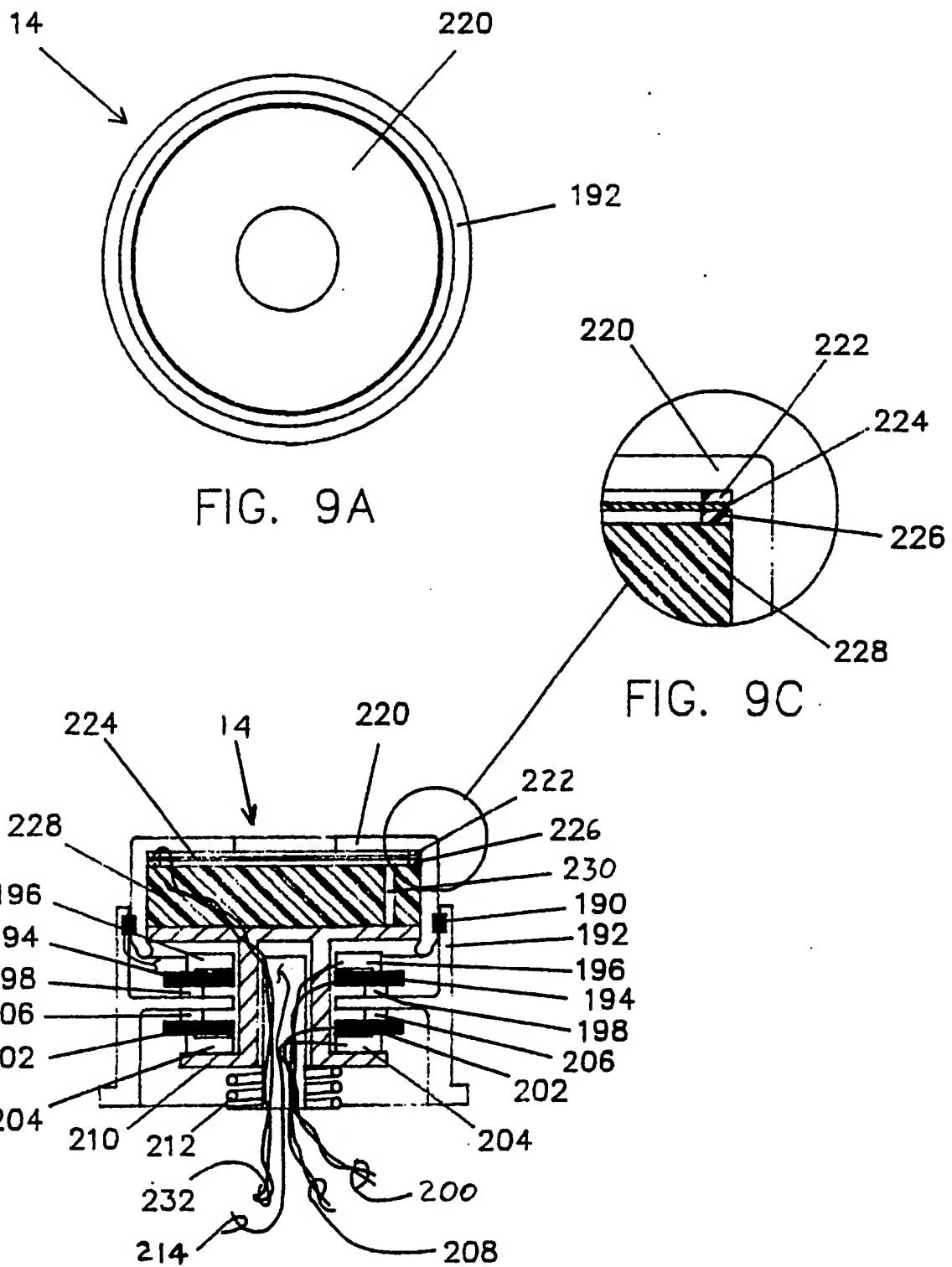


FIG. 9B

16 / 21

FIG. 10 A

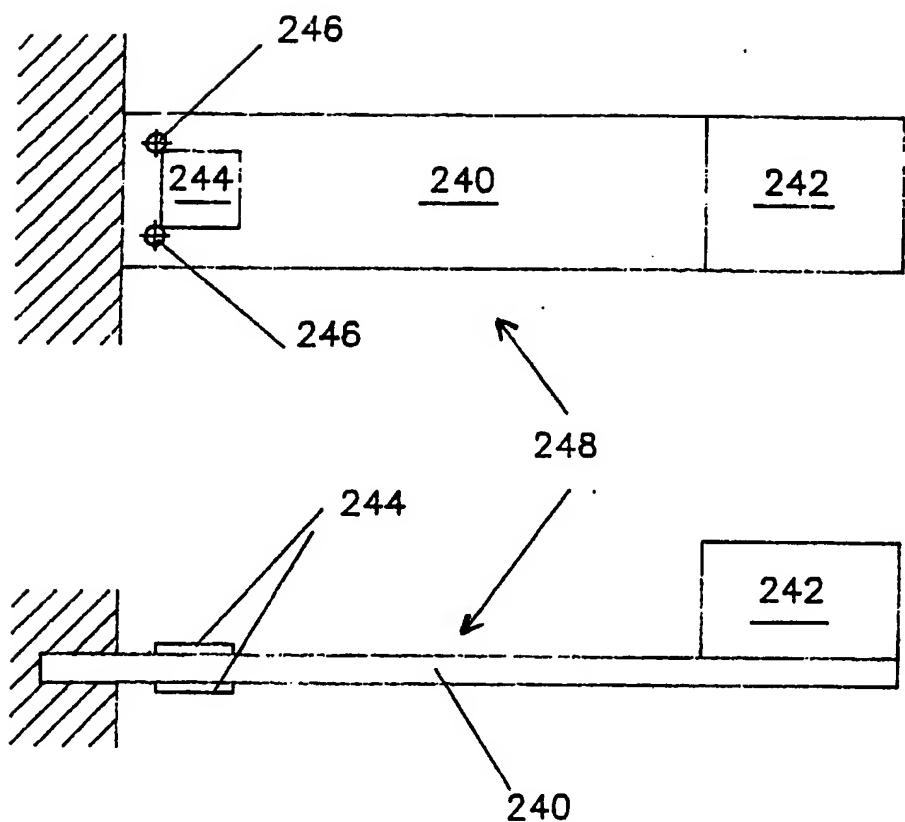
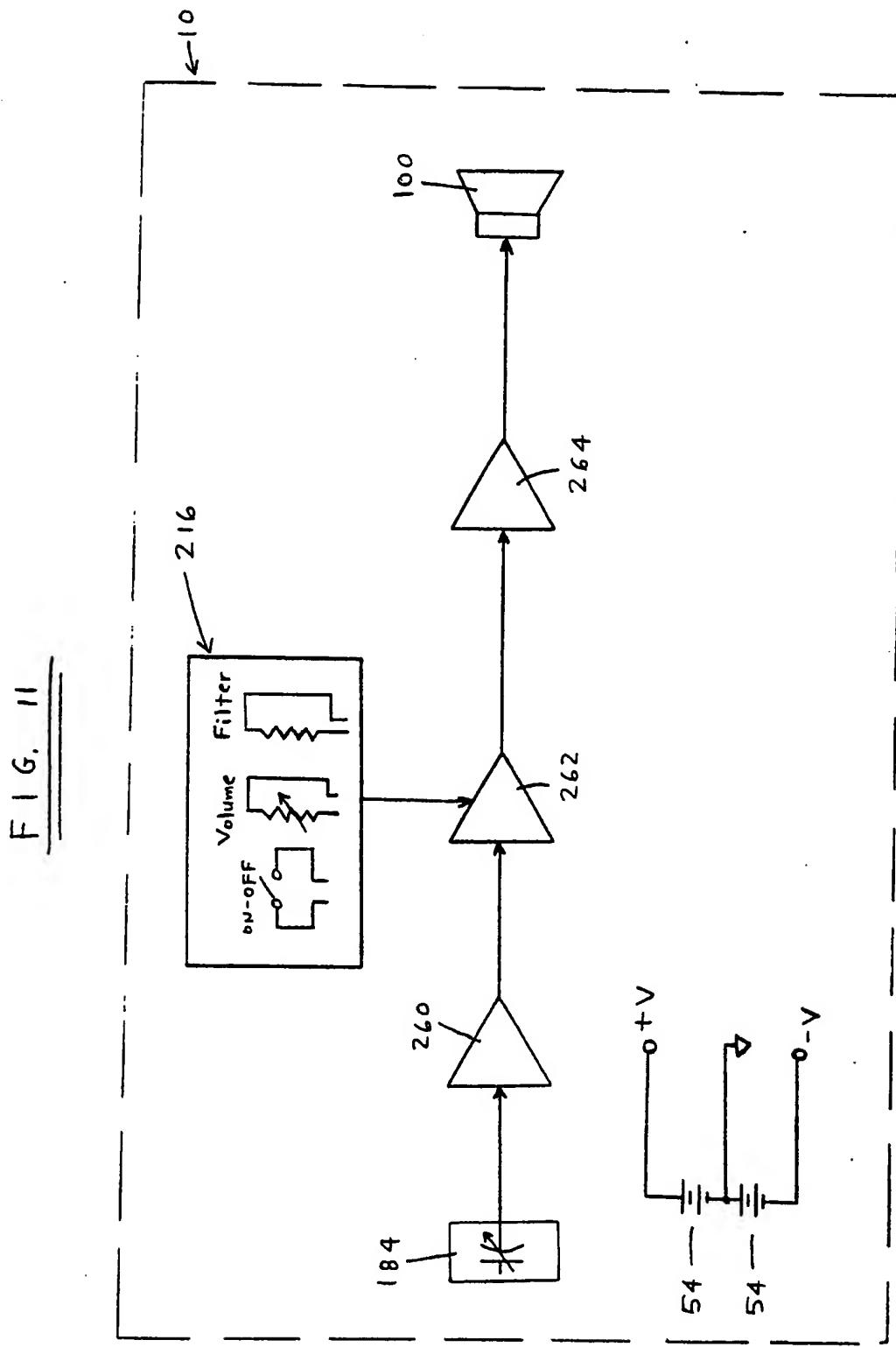


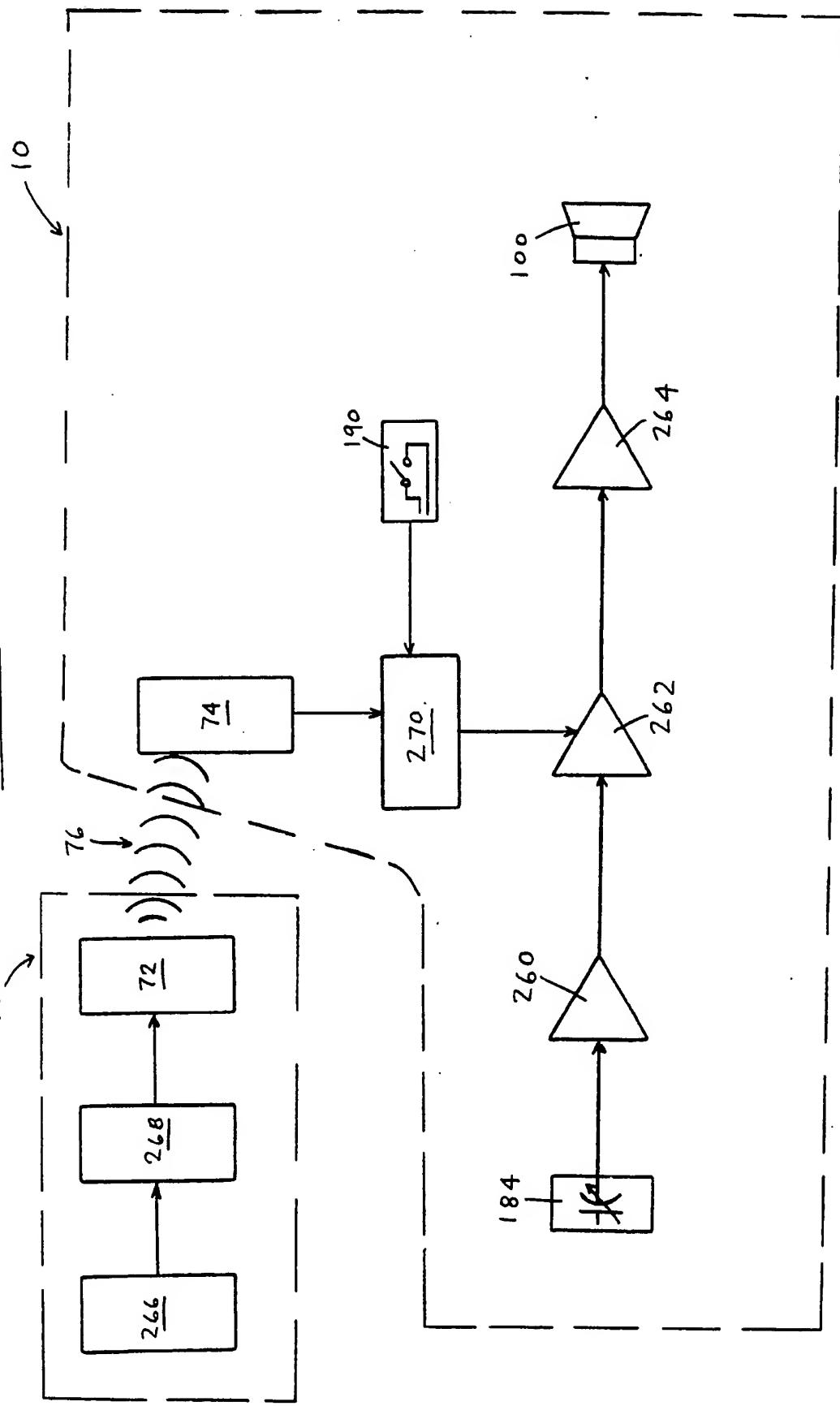
FIG. 10 B

17 / 21



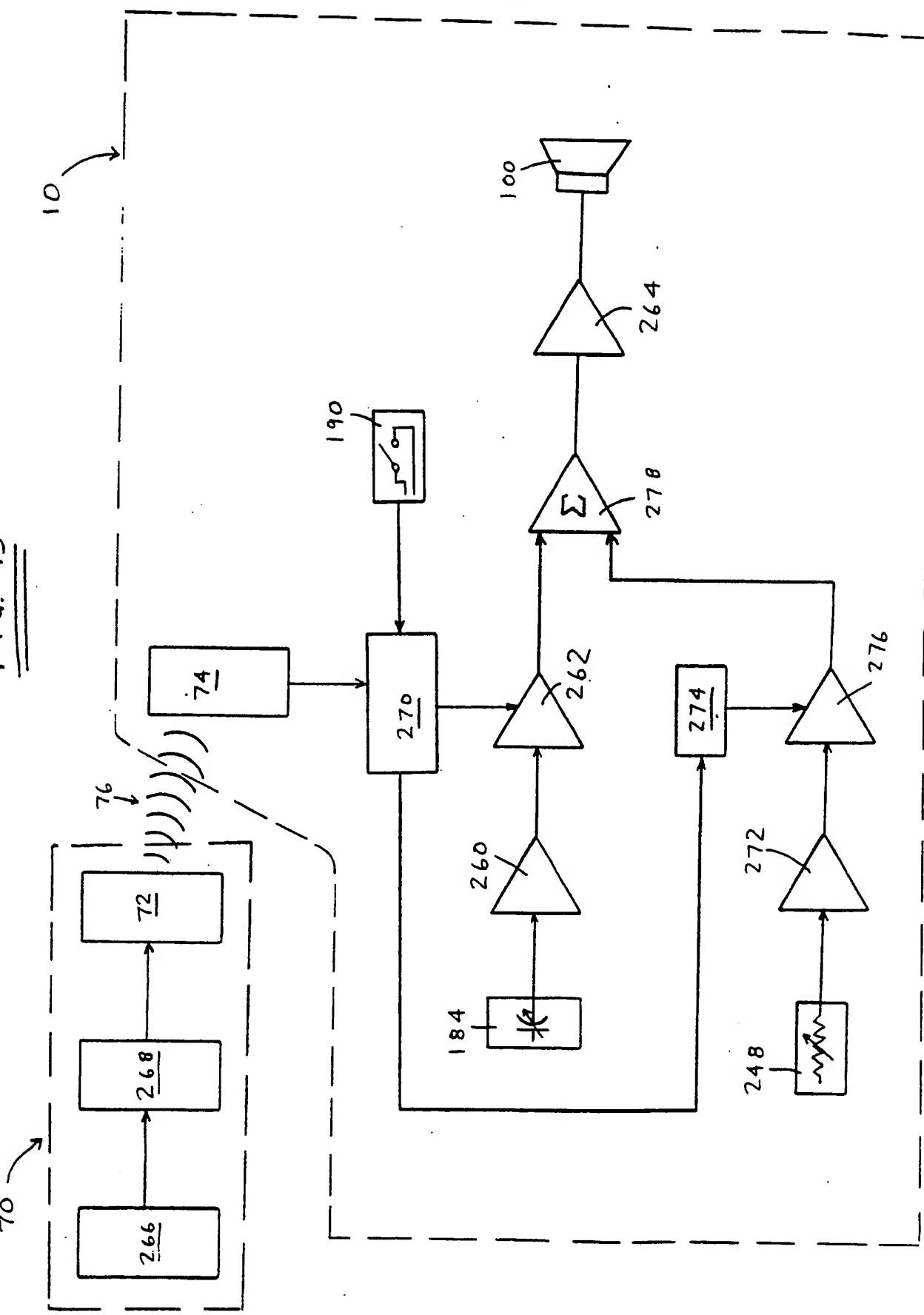
18 / 21

FIG. 12



19 / 21

FIG. 13



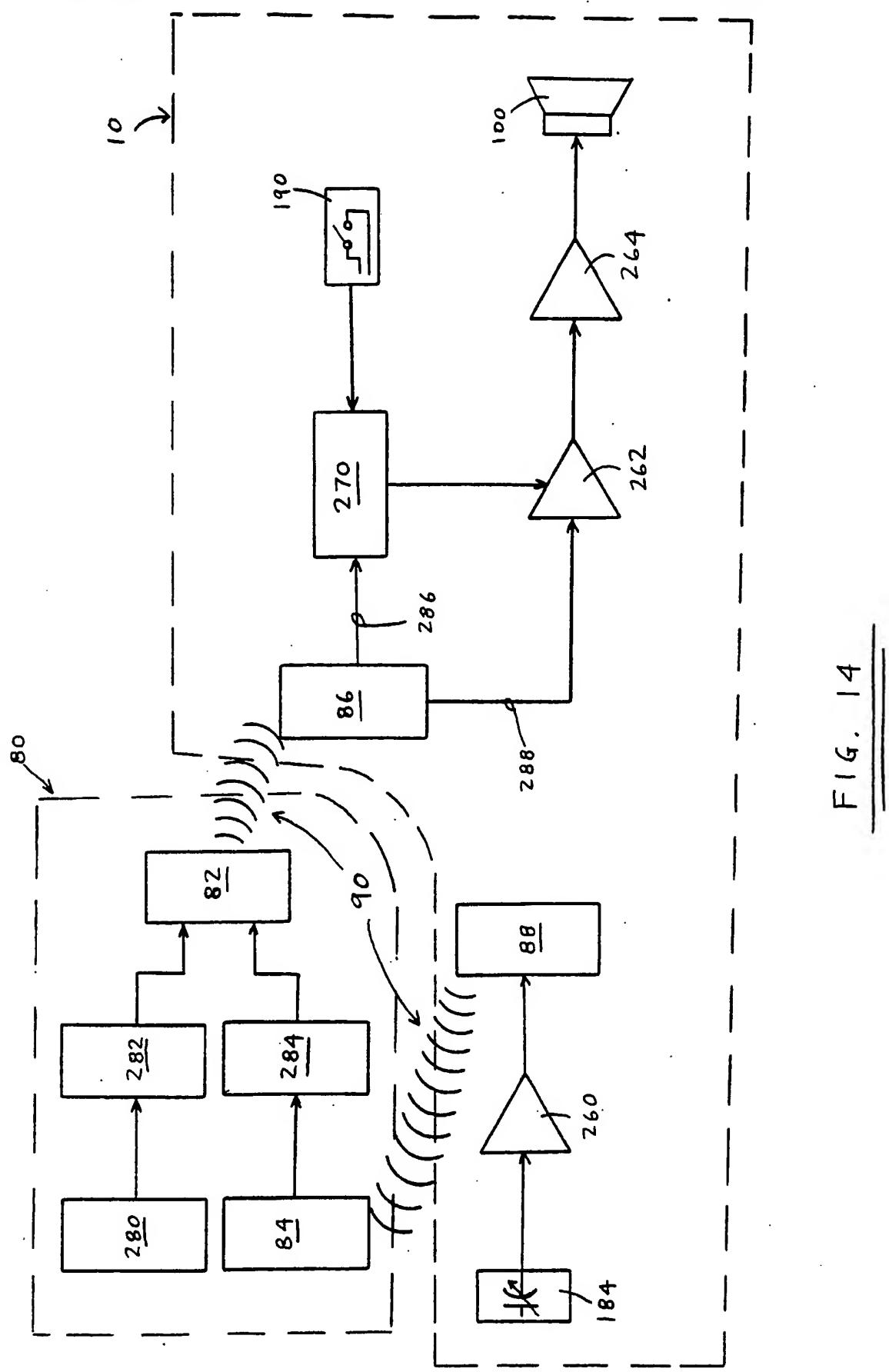
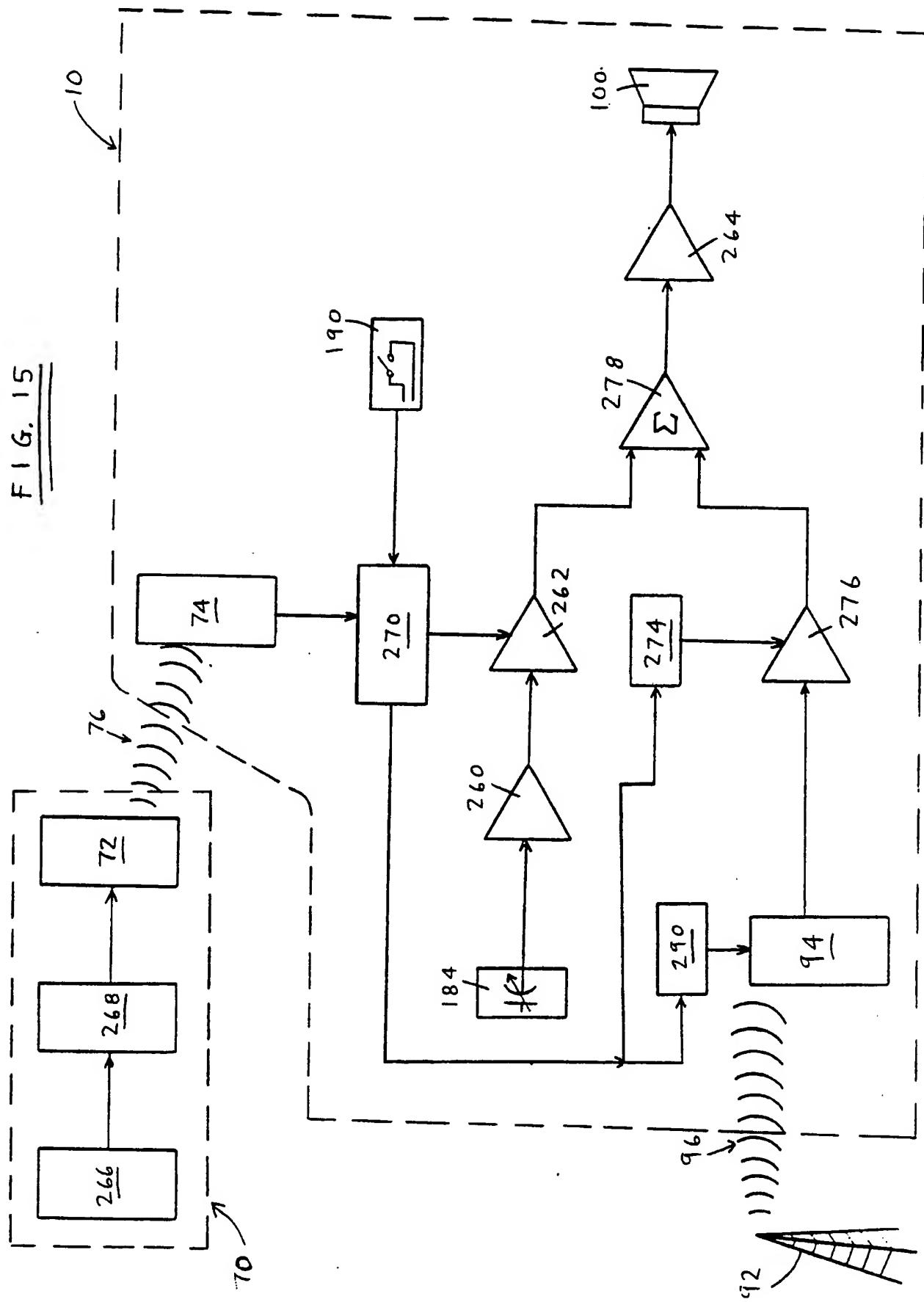


FIG. 14

21 / 21



INTERNATIONAL SEARCH REPORT

International Application No. PCT/US92/00380

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) *

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5): H04R 25/00;

US CL : 381/68,68.2-69.4,68.6,69; 600/25; 128/420.5,420.6

II. FIELDS SEARCHED

Classification System	Minimum Documentation Searched ?	
	Classification Symbols	
U.S.	381/68,68.2-68.4,68.6,69,151,110,122,186,203; 181/130,135 128/420.5,420.6; 600/25	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched. *		

III. DOCUMENTS CONSIDERED TO BE RELEVANT *

Category *	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	US, A, 3,527,901 (GEIB) 08 SEPTEMBER 1970	1,2,19-22,46
Y	See the entire document.	3-18,23-33
X	US, A, 4,901,354 (GOLLMAR) 13 FEBRUARY 1990	40
Y	See col. 2, line 63 through column 3, line 44.	23-32,41-44
X	US, A, 3,746,789 (ALCIVAR) 17 JULY 1973	40,45
Y	See column 1, line 62 through column 5, line 55.	23,33
Y	US, A, 4,622,692 (COLE) 11 NOVEMBER 1986	3-8,18
	See column 3, line 14 through column 4, line 31.	
Y	US, A, 3,873,784 (DOSCHEK) 25 MARCH 1975	9-12,13-17
	See figs. 18,27,38.	
Y	US, A, 4,920,570 (WEST) 24 APRIL 1990	35,36
	See the entire document.	
Y	US, A, 4,334,315 (ONO) 08 JUNE 1982	35,36
	See fig. 12.	
Y	US, A, 4,150,262 (ONO) 17 APRIL 1979	24-27,41-44
	See fig. 12.	

* Special categories of cited documents: *

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

** later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

*** document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

**** document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

***** document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search

19 FEBRUARY 1992

Date of Mailing of this International Search Report

25 MAR 1992

International Searching Authority

Signature of Authorized Officer

ISA/US

JASON CHAN

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

Y	US, A, 4,880,076 (AHLBERG) 14 NOVEMBER 1989 See column 5, lines 16-27.	13,14
Y	US, A, 4,329,676 (McDONALD) 11 MAY 1982 See column 6, lines 1-4.	29
Y	US, A, 4,068,090 (KOMATSU) 10 JANUARY 1978 See column 8, lines 41-42 and fig. 12.	30-32

✓ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE:

This International search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. Claim numbers because they relate to subject matter^{1,2} not required to be searched by this Authority, namely:

2. Claim numbers because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out^{1,2}, specifically:

3. Claim numbers, because they are dependent claims not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING:

This International Searching Authority found multiple inventions in this international application as follows:

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4. As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remarks on Protest

- The additional search fees were accompanied by applicant's protest.
- No protest accompanied the payment of additional search fees.

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